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INTERCHANGEABLE END EFFECTOR TOOLS UTILIZED ON THE PFMA

FINAL REPORT

February 27, 1992

PREPARED FOR:

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CONTRACT NO.: NAS8-36307, Modification No.'s 17,18

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SUBJECT: Final Report - Interchangeable End Effector Tools Utilized on the PFMA

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DATE OF PUBLICATION: February 27, 1992

The enclosed R&D Final Report provides a description of the work performed under the subject contract for the period, September 1988 to June 1991.

Sincerely,

SRS TECHNOLOGIES
Systems Technology Division

Paul A. Gierow

Paul A. Gierow
Project Engineer

PAG/kct

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FOREWORD

This final report was prepared by SRS Technologies under Contract No. NAS8-36307 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction the Information and Electronics Systems Laboratory Guidance Control and Optical Systems Division with Mr. Tom Bryan as Project Manager.

This report describes the work performed by SRS Technologies, Aerospace Systems Directorate, during the September, 1988 - June, 1991 period. Significant SRS Technologies contributors to this effort and final report are:

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1.0 INTRODUCTION

Under Contract No. NAS8-36307, Modification 9, an instrumented task board, used for measuring forces applied by the Protoflight Manipulator Arm (PFMA) to the task board, was fabricated and delivered to Marshall Space Flight Center. Under Modification 17, SRS Technologies phased out the existing IBM compatible data acquisition system, used with a instrumented task board, and integrated the force measuring electronic hardware in with the Macintosh II data acquisition system. The purpose of this change was to acquire all data with the same time tag, allowing easier and more accurate data reduction in addition to real-time graphics. A three-dimensional optical position sensing system for determining the location of the PFMA's end effector in reference to the center of the instrumented task board was also designed and delivered under Modification 17.

Under Modification 18 of Contract No. NAS8-36307, an improved task board was fabricated which included an improved instrumented beam design. The modified design of the task board improved the force/torque measurement system by increasing the sensitivity, reliability, load range and ease of maintenance. A calibration panel for the optical position system was also designed and fabricated. The calibration method developed for the position sensors enhanced the performance of the sensors as well as simplified the installation and calibration procedures required.

The modifications made under this effort expanded the capabilities of the task board system. The system developed determines the arm's position relative to the task board and measures the signals to the joints resulting from the operator's control signals in addition to the task board forces. The software and hardware required to calculate and record the position of the PFMA during the performance of tasks with the instrumented task board were defined, designed and delivered to MSFC. PFMA joint input signals can be measured from a breakout box to evaluate the sensitivity or response of the arm operation to control commands. The data processing system provides the capability for post processing of time-history graphics and plots of the PFMA positions, the operator's actions, and the PFMA servo reactions in addition to real-time force and position sensor data presentation.

2.0 INSTRUMENTED TASK BOARD

Figure 2-1 shows the modified instrumented task board that was installed at MSFC. The complete design drawings of the task board and stand are included in the appendix.

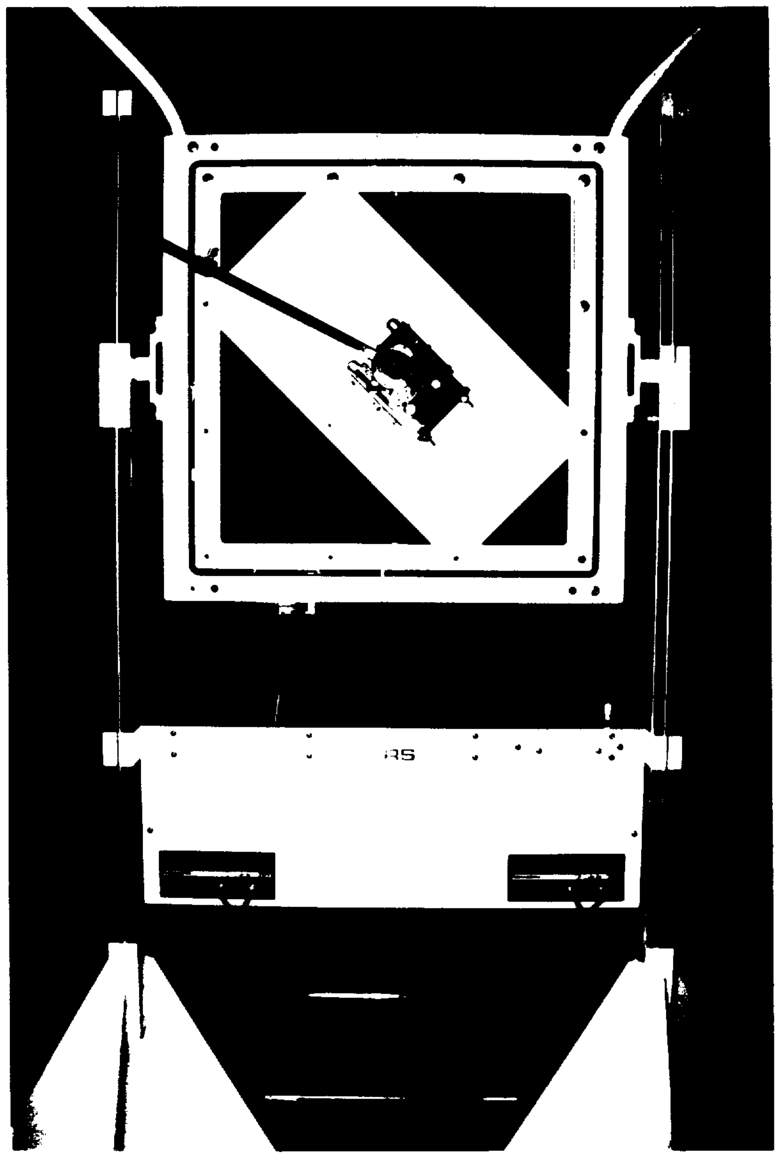


Figure 2-1 Modified Instrumented Task Board Installed at MSFC

The instrumented task board system consists of an inner task frame that is instrumented to measure the forces and torques placed on the board. The inner frame accepts 19" task panels which are interchangeable. A 4-point suspension system design is used to fully support the inner

frame of the task board. Cantilever beams instrumented with strain gauges and signal conditioners are used in order to determine the forces and torques placed on the task board. The instrumented beam design incorporates low friction instrument linear bearings combined with a spherical bearing. The instrumented beam design results in no axial loads or torques placed on the cantilevered beams. Incorporating the low friction axial and rotational mounting methods to the task board results in a perpendicularly applied load to each instrumented beam. The unique mounting method enables the instrumented beam/strain gauges to measure components of the load on the beams allowing for force component measurements. The modified task board design also includes a self-aligning mounting method for the instrumented beams. The design aids in installation and calibration the system. The design allows the beams to be replaced or repaired easily if necessary.

The swivel support frame design allows for the task board to be vertically positioned at a height range of 3-5 feet and to be rotated and locked in the desired position. A machine screw jack is used with linear bearings and hardened shafts to vertically position the task board. The combination of linear bearings and hardened ground shafts enables the task board to be positioned easily. The swivel support design has a vernier scale and locking mechanism to rotate the task board to the desired position. The frame design includes the capability to raise, lower and rotate the task board.

3.0 DATA ACQUISITION SYSTEM

The data acquisition system monitors and records all the interaction of the PFMA operator with the instrumented task board and records each position sensor unit. The data acquisition system uses a Macintosh II, LabVIEW control software, and an analog-to-digital input/output PC board in series with an analog multiplexer board. The system's set up is shown in Figure 3-1.

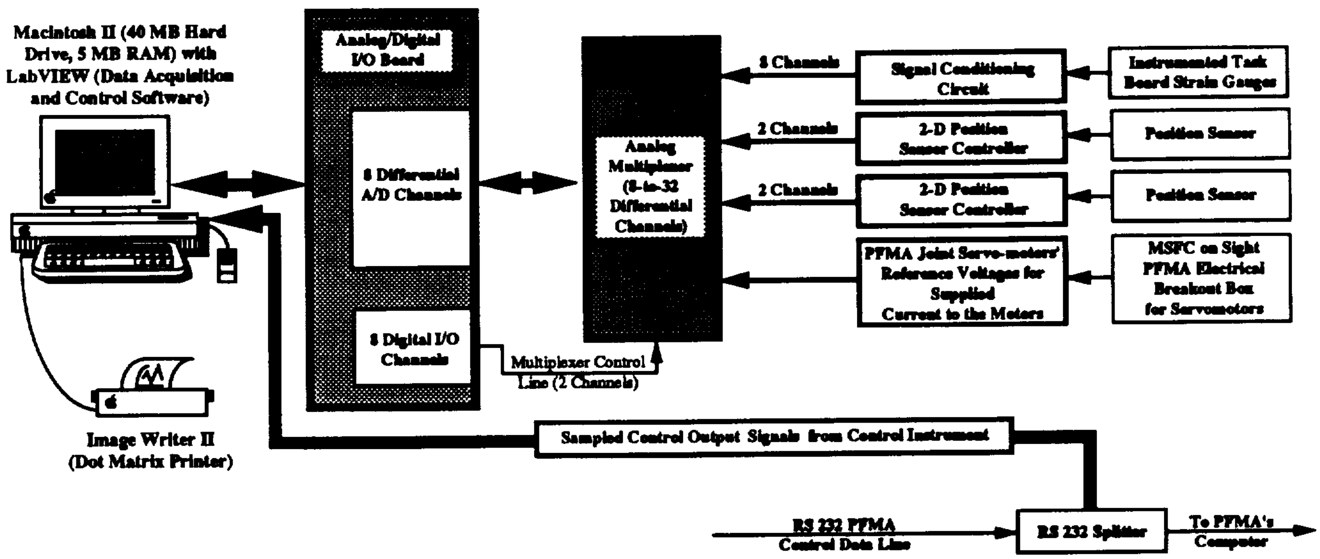


Figure 3-1 Electronic Data Acquisition System

The Macintosh II consists of a 40 megabyte hard drive, 4 megabyte extended RAM, 4 bit video monitor card, color high-resolution monitor, and standard keyboard. The analog-to-digital input/output board (NB-MIO-16L-25) and the analog multiplexer (AMUX-64), developed by National Instruments, provides the computer with the ability to perform data acquisition on a maximum of 64 channels and control up to 256 logical operations. The computer system is controlled with LabVIEW, a data acquisition and control graphical software developed by National Instruments. Hard copies of the raw test data and graphs of the test performance are obtained from the Image Writer II, a dot matrix printer. This computer system provides a user friendly environment along with efficiency.

The task board system was integrated into the MacIntosh II data acquisition system. This required proper configuration of cables and the A-to-D board's input terminals in conjunction with modifications to the existing software. The software was modified to incorporate the increased force measurement range and the capability of initializing all 3-D force measurements to zero. The previous instrumented task board was limited to measuring forces up to 30 pounds due to the

structure of the joysticks used. The joysticks used in the modified instrumented task board are capable of linearly measuring over 100 pounds of force. As a result, the maximum force measuring range of the modified task board was set at 100 pounds (accurate resolution of 0.1 pounds) in the circuitry and software. In addition to this software change, the data acquisition software was modified to include an option of selecting whether or not the operator would like to initialize all measured forces to zero. This is necessary in order to take into account the difference in weight of the various task board panels used on the instrumented task board.

3.1 Data Acquisition Software

LabVIEW serves as a software driver and controller for the NB-MBIO-16 and AMUX-64 hardware data acquisition boards installed in the Macintosh II. LabVIEW is a complete programming environment which allows the user to construct virtual instruments (VI's) that control and record operations that are required. LabVIEW sub-virtual instruments were constructed to perform the requirements of the demonstrations. The final instrument design includes integration of the sub-virtual instruments into a single virtual instrument for simultaneous data acquisition and real-time monitoring.

The building block of LabVIEW is the Virtual Instrument (VI). The Virtual Instruments in LabVIEW are the software components of the complete data acquisition and control system installed in the Macintosh II. Each VI has a front panel which specifies the inputs and outputs of the program. Figure 3-2 represents the controls and indicators of the measurement system. Behind the front panel in LabVIEW is a block diagram which represents the actual executable program. The diagram represents graphical programming functions that are standard in any programming environment. Any virtual instrument that is designed can be represented as an icon that can be included in other VI's. The hierarchical structure of LabVIEW enables the user to construct complicated control and acquisition systems from combining the Virtual Instruments into one complete Virtual Instrument.

3.2 Requirements for Arm Sensor and Data Acquisition System

The data acquisition system on the Macintosh II for the arm sensor system is driven by the LabVIEW software. The data acquisition requirements of the arm sensor system include reading and storing to disk analog signals from the strain gage conditioning circuits from the task board, position sensors and current proportional voltages from the PFMA servo motors. Information from the PFMA operator via RS-232 data lines was included in the data acquisition and storage system on the Macintosh II.

The operations of the data acquisition and storage system are shown in Figure 3-3.

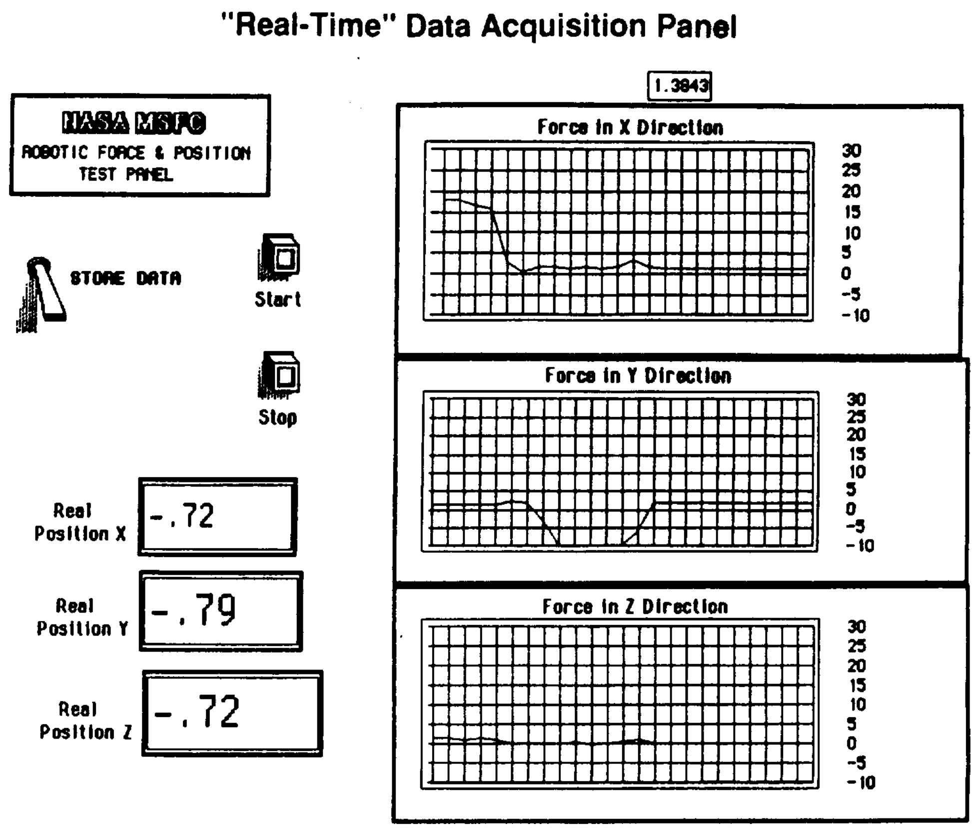


Figure 3-2 Front Panel Controls and Indicators for Task Board

Force Measurements

- Acquisition of the Strain Signals from the Instrumented Task Board
- Conversion of the Strain Data to Force Data
- Calculation, Recording and Real Time Graphical Presentation of the Three-Dimensional Forces Applied to the Instrumented Task Board

Position Measurements

- Acquisition of the Position Sensors' Outputs
- Calculation of the PFMA's Three-Dimensional Position Relative to a Chosen Origin
- Recording and Graphical or Numerical Presenting the Three-Dimensional Location of the PFMA in Reference to a Chosen Origin

PFMA Servomotor Measurements

- Acquisition of the Current Proportional Voltages from the PFMA's Servomotors
- Calculation of Power Used By each Servomotor, During Operations, if Required

PFMA Control Line Information

- Record all PFMA's Control Line Information which is Transmitted over an RS-232 Data Bus at a rate of 9600 Baud.

Figure 3-3 Data Acquisition and Storage System Operations Summary

A load measurement VI was written consisting of data acquisition and storage of the analog channels of interest. A double buffer acquisition system is used in LabVIEW. The system allows the programmer to store information in a buffer while scanning the channels of interest on the A/D board. The buffer is then periodically read and stored to the desired output file on the computer. The data is also plotted on the screen while simultaneous data acquisitions are occurring. An external gate is also used for triggering of data acquisitions. The external gate enables data acquisitions while the gate is held in a high position. The external gate enables the board to perform a scan of the channels at a high rate but allow for a delay time between each scan. The delay time is determined by the desired acquisition rate.

The operator commands via the RS-232 data line can be read by LabVIEW using an RS-422 port read virtual instrument. The instrument reads the contents of the RS-422 buffer. The buffer size can be configured by the user. Simultaneous analog data acquisition and RS-422 buffer storage is available if desired. The RS-422 buffer read VI can be incorporated into the data acquisition VI.

3.3 Development of RS-422 'Listen' Program in LabVIEW Environment

A LabVIEW virtual instrument was written that reads the operator commands via the RS-422 data line. The instrument reads the contents of the RS-422 buffer on the Mac II. The buffer size is configured such that the buffer is not overwritten during file storage of data on the Mac II. A file transfer program was used to transfer data to the virtual instrument through the modem port on the Mac II. File transfers of ASCII data were accomplished at a rate of 9600 baud. Another virtual instrument was constructed to periodically read the contents of the buffer and store the information on disc. The virtual instrument can be integrated with the analog data acquisition virtual instrument.

4.0 OPTICAL POSITION SENSOR SYSTEM

The instrumented task board was modified during the effort to include a three-dimensional position sensoring system. The system enables the controller to know the precise coordinate or location of the end effector tool being used, in reference to the center of the board. This system is comprised of two Hamamatus (C2399) two-dimensional position sensor systems. Each position sensor system is a compact, high-resolution position sensor using a non-discrete position-sensitive detector. The non-discrete position-sensitive detector enables high-speed measurement of a moving spot with high accuracy. The position sensor is an opto-electric unit which measures the position of a single-point of infrared light focused on the sensor head. The two dimensional position sensor systems are comprised of a system controller, an infrared lens and sensor head, and a seven infrared LED cluster target.

Each two-dimensional position sensor is monitored by the Macintosh II through an analog-to-digital input/output board. The position of the target, which is mounted near the PFMA's end effector, is recorded by the sensor head. The two dimensional coordinates are transmitted as an analog input to position controller. The sensor heads are located at 90° angles from each other relative to the center of the instrumentation board.

4.1 Sensor Description

This system is comprised of two Hamamatus (C2399-00) two-dimensional position sensor systems. The C2399-00 Position Sensor is an opto-electric position sensing unit designed to take advantage of the Position-Sensitive Detector (PSD), and measures the two-dimensional position of a light spot. The PSD is a light detecting element which makes use of a photo-diode. These functions enable the user to provide continuous position measuring and high-accuracy measuring for a moving light spot at high speed because it is a non-discrete type, and to obtain a quick response because it does not require scanning.

The C2399-00 lights the infrared LED corresponding to a pulse output from the control unit and measures the position data by means of 312.5 Hz frequencies. An infrared filter and a built-in background-light eliminating circuit is provided in the sensor head; therefore, no light intensity other than the LED target can affect measuring An accurate position measurement is performed optically with the LED target fitted on the object to be measured. This prevents position detection errors due to noise conduction from other objects, as may be encountered with ordinary vibrometers or accelerometers. Upon examination of the position sensor controller, it was noted that the manufacturer had modified their advertised position sensor system in order to eliminate cross talk between systems, when using two systems together to obtain a three-dimensional

location of an object. This was confirmed through testing of each position sensor system in which the position sensing units performed as expected.

4.2 Calibration of the 3-D Target Tracking System

Calibration hardware was designed and fabricated for calibrating the 3-D target tracking system. The work included installation and verification of the calibration unit, procedures for setting up sensors and calibration of the system, and the development of data acquisition and display software to assist in calibrating the system. Figure 4-1 shows the calibration unit mounted on the modified task board that was installed at MSFC.

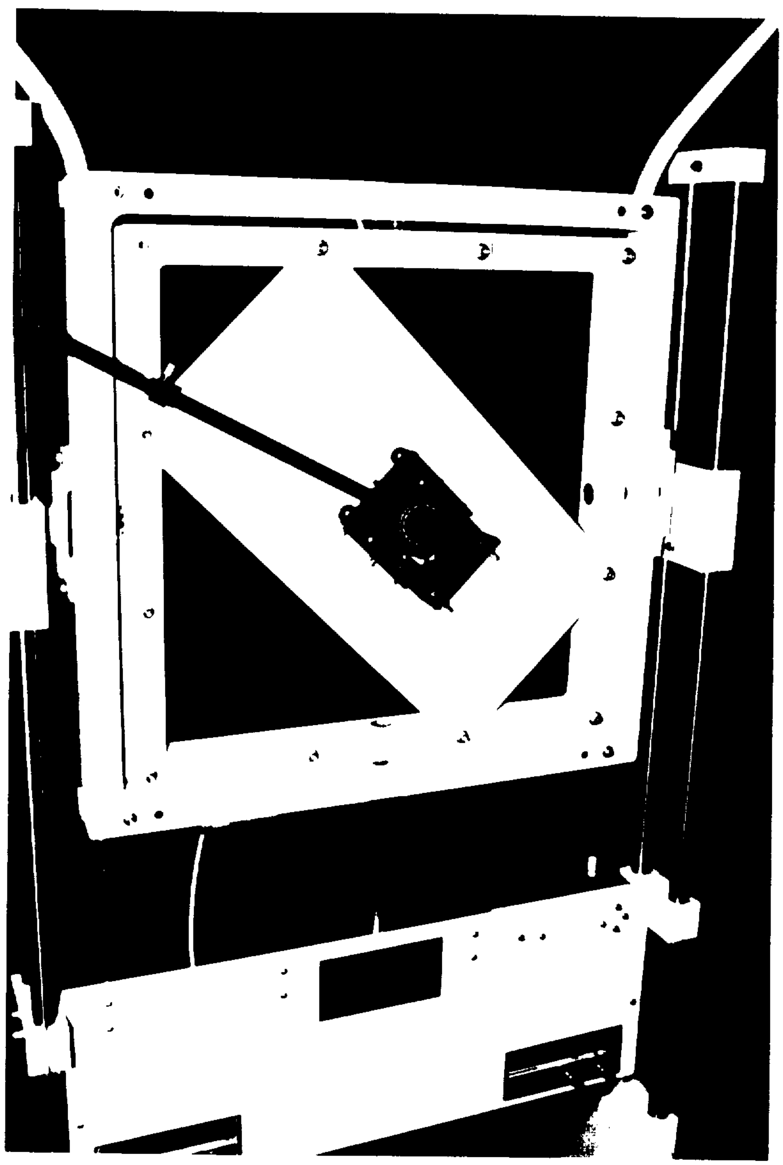


Figure 4-1 Installation of the Calibration Unit at MSFC

More detailed views of the calibration unit are shown in Figure 4-2. This section describes in detail the process used for the calibration of the target tracking system each time that reassembly is required. The section includes a description of the system's configuration, procedure for setting up sensors, alignment of sensors, scaling of outputs, and determining the distance between the origin and each sensor.

The configuration of the IR target tracking system is such that the sensors are mounted approximately 74 inches away from the center point of the task board, along 45° diagonal lines from the X and Y axis in the X-Y plane, and approximately 4 inches in the positive Z direction, as shown in Figure 4-3. The area of coverage of the sensor heads is a 20° square-cone shape. By placing the sensor heads 90° apart, the three-dimensional envelope of coverage resembles an odd shaped box, which covers the area in front of the task board as shown in Figure 4-4. Each position sensor senses a target in a two-dimensional plane. The output of the position sensor control unit is in the form of ±5 volts, for each of the two-dimensions seen, corresponding to the location in which the infrared signal is projected onto the screen of the sensor. The output of the position sensor control unit describes a unique line in space, originating from the center of the position sensor's lens, as shown in Figure 4-3 and Figure 4-4. The output of the position sensor along each axis in a two-dimensional plane, as seen by a position sensor, varies with the distance away from that plane.

A procedure was developed for setting up the 3-D target tracking system which reduces the time required for calibration of the system, upon any reassembling of the system. By following this procedure for setting up the sensors and sensor's support structures, the initial position of the sensors will be in the approximate required location; therefore, requiring only slight, if any, adjustments to the sensors' support structures and system software for the calibration of the 3-D target tracking system. The first step is to place the sensor mounting rods into the mounting clamps located on the back of the external task board frame, as shown in Figure 4-5A. The clamps should be tightened down in the position where all alignment marks on each piece are lined up. This will position the mounting rods approximately parallel to the task board. The second step is to attach the sensors to the black support rods' mounting plate by screwing the adjustment screw into the bottom of the sensor, as shown in Figure 4-5B. Make sure that the alignment marks, located at each pivot point, are lined up. The third step is to slide the black support rod into the tee joint, located at the top of the mounting rod, until the marked point is reached. Then twist the support rod clockwise or counter clockwise until alignment marks are aligned and tighten the tee joint collars, as shown in Figure 4-5C.

Figure 4-2 Calibration Unit Used for Alignment and Calibration of Target Tracking System

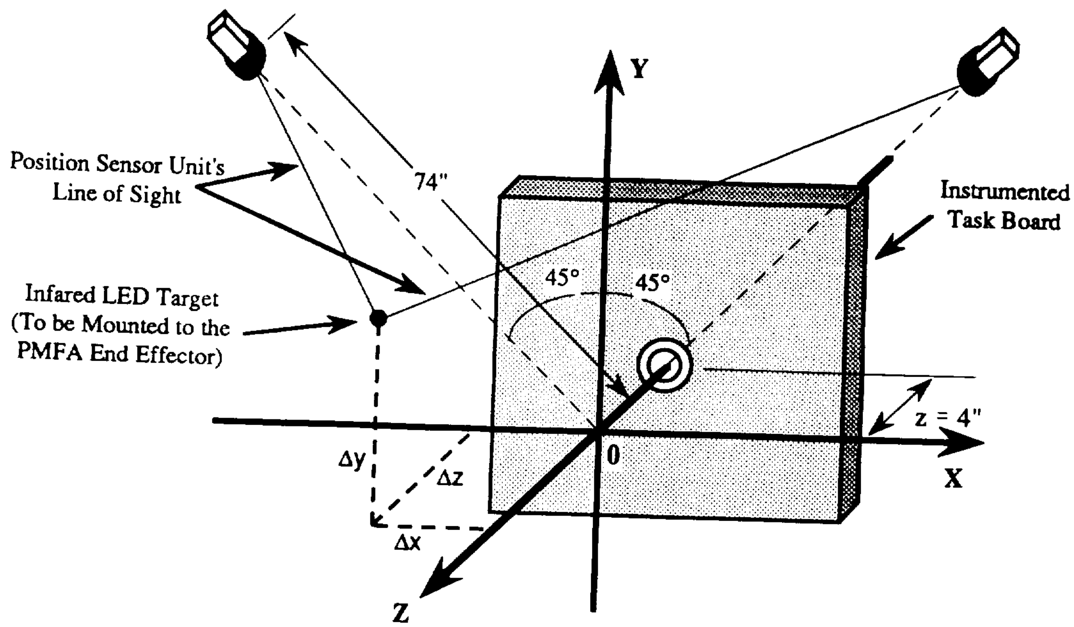


Figure 4-3 Three-Dimensional Position Sensing System Layout

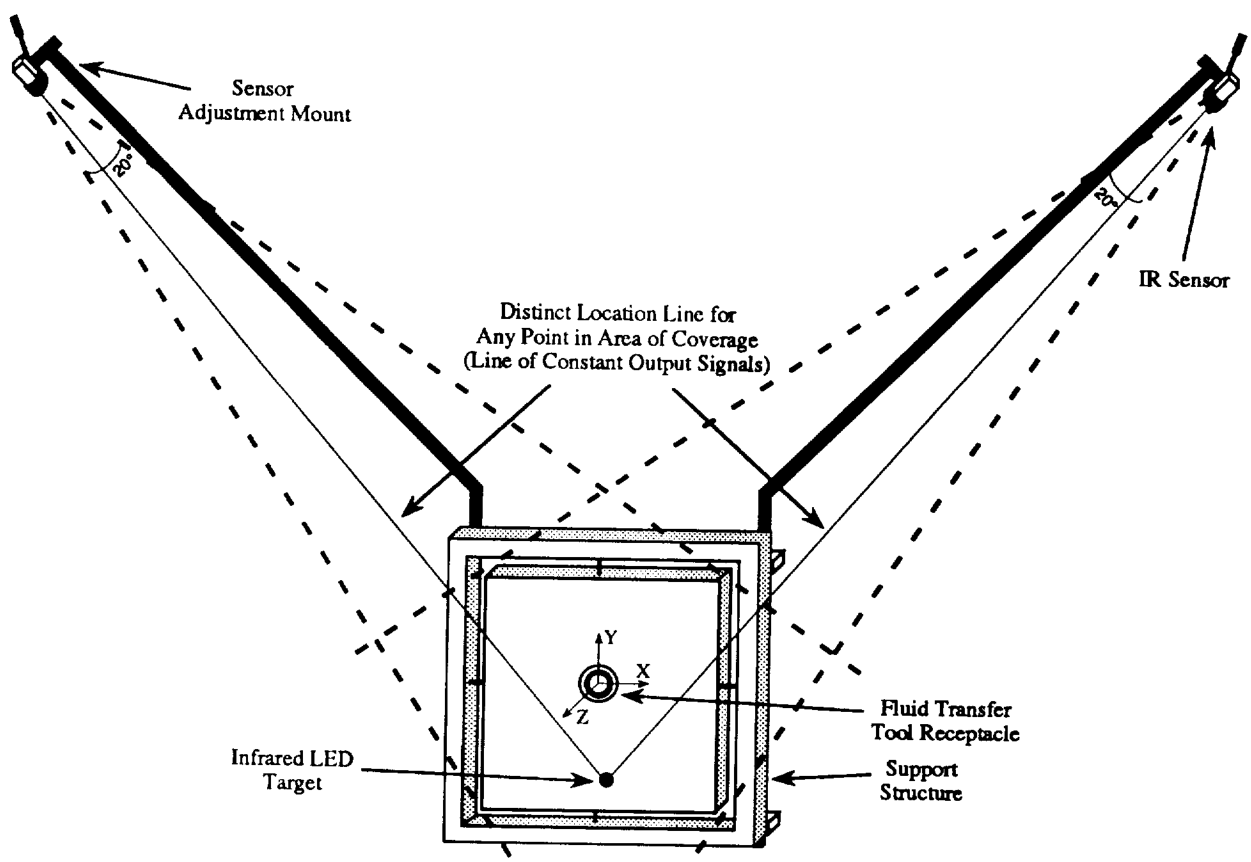


Figure 4-4 Task Board IR Target Tracking System Configuration

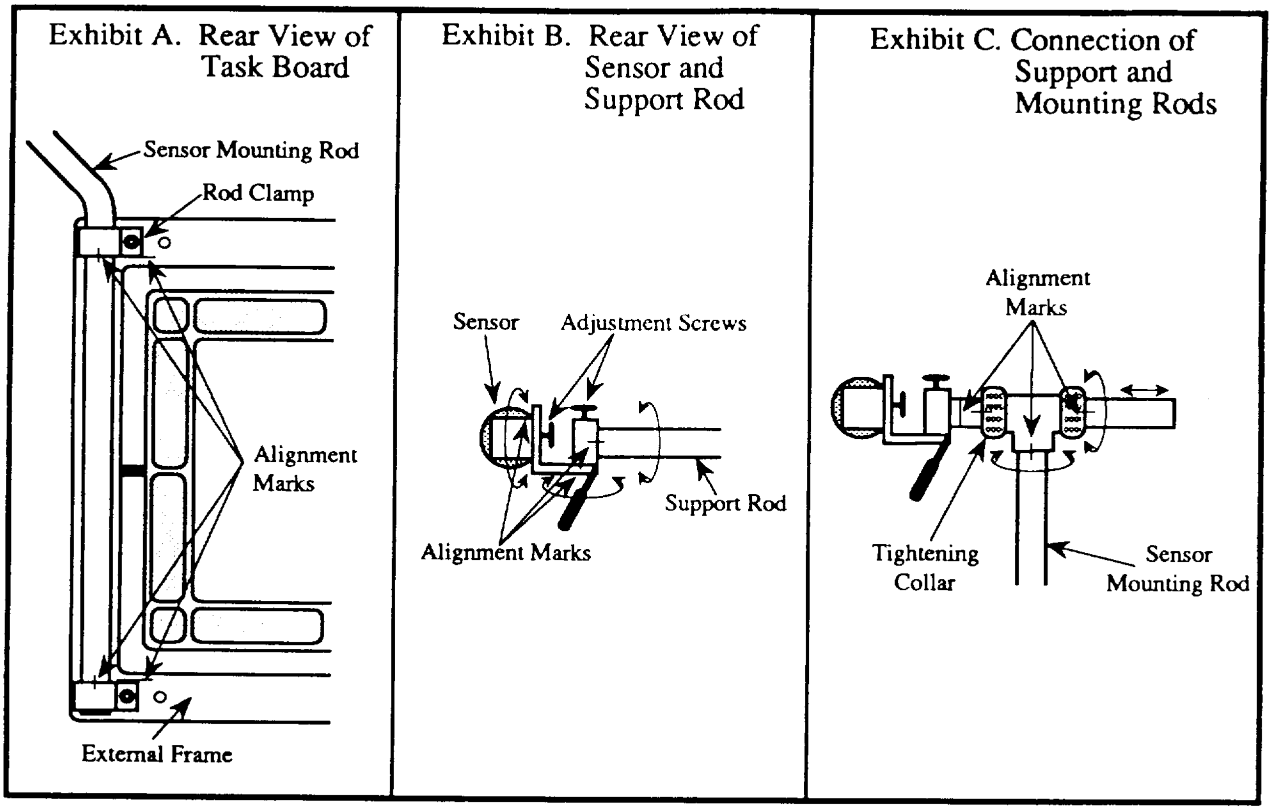


Figure 4-5 Sensor Support Structure Setup

Once the sensors are setup according to the procedure described above, they will be in the approximate required alignment position. The sensors' alignment accuracy is increased by calibrating each sensor separately, due to the independence of the 2-D position sensor systems, though the use of the calibration unit and calibration programs. The final alignment of a sensor is accomplished by moving the IR target in a circular path, on a plane perpendicular to the front of the sensor, and adjusting the sensor until a circular path, from the plot of the sensor's output, is obtained. If the sensor is misaligned, the plot of the sensor's output is an elliptical shape. Once the sensor is aligned, sensor voltage output for incremental displacement along the X and Y axis should be recorded in order to determine the voltage vs. displacement scaling for each sensor's outputs at a set distance away from the predefined origin.

The calibration unit is set up by first, bolting on the calibration panel to the internal task board frame. The calibration unit should then be mounted on the panel, in the marked bolt holes, oriented with the degree scale on the calibration unit facing the sensor that is to be aligned, as shown in Figure 4-6. This will allow the IR target, located on the arm of the calibration unit, to

spin approximately 200° about the center of a predefined origin, shown in Figure 4-6 (view A-A). The target can be moved along the calibration unit's arm and locked in to place every inch increment, allow for scaling and transforming the sensor's output voltage to displacement.

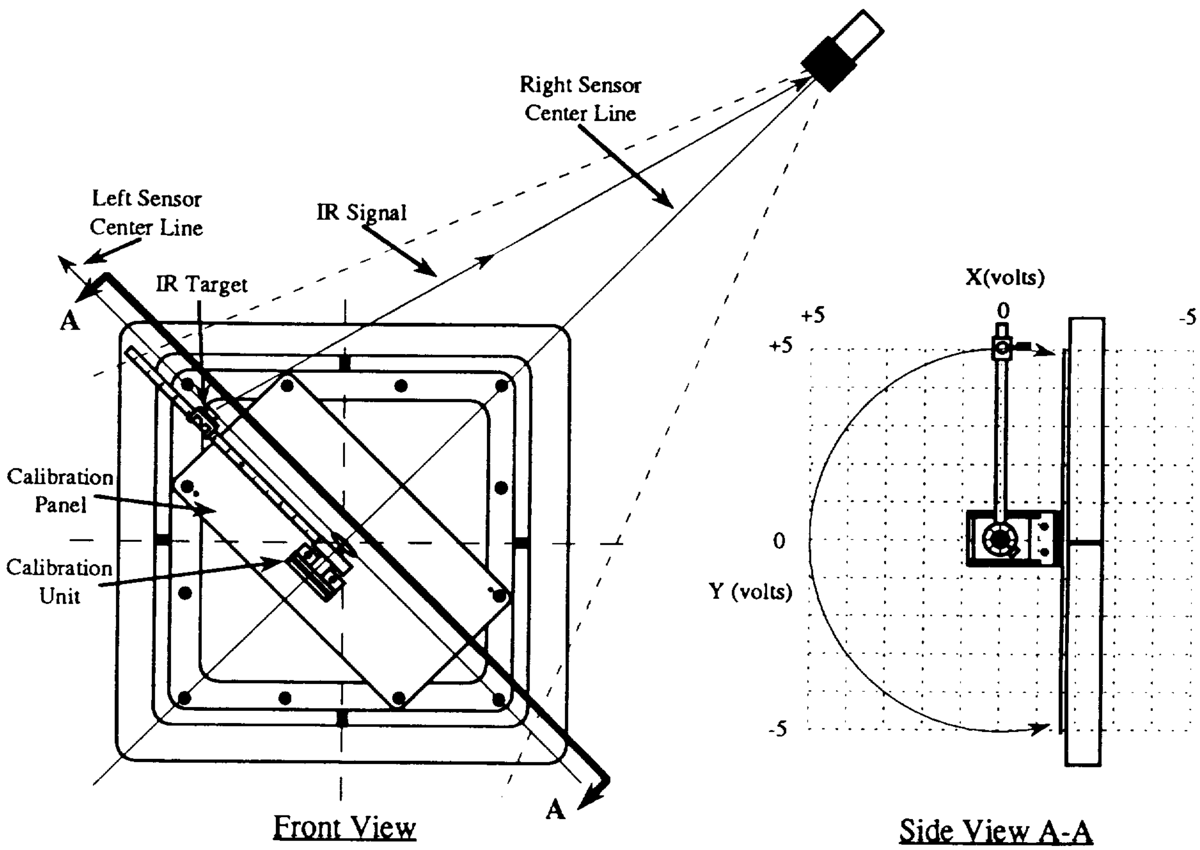


Figure 4-6 Right Sensor Alignment and Output Scaling Using the Calibration Unit

The procedure for aligning each sensor is to lock the IR target, located on the calibration unit's arm, into a set location (approximately 10" to 13"), then record the X and Y output voltages while spinning the arm from one side of the board to the other, plot the output voltages to determine if the resulting output produces a circle shape graph, and realign sensor, if necessary. Repeat the procedure until the sensor is properly aligned. The data acquisition and plotting for this procedure is performed with a program called "Sensor Alignment/Scale Instr.", developed in LabVIEW. Once the program is opened and operating, the data acquisition and recording is started by depressing the START button on the front panel of the program, shown in Figure 4-7, with the mouse. The unit's arm, with the target locked into place, should then be rotated from one side of the board to the other, depressing the STOP button upon completion of the rotation. During the data acquisition, the real-time X and Y output of the sensor will be displayed on the screen with a

digital readout. When the STOP button is depressed, the array of data recorded during the acquisition is plotted to the sensor's X-Y output graph located on the front panel of the program. This X-Y graph is a time history representation of what the sensor viewed. The information from this graph will assist in determining the proper adjustments of the sensor to correct any misalignment. This complete alignment procedure should be repeated for both sensors. Note that the graph and digital readouts located on the top half of the front panel are the outputs of the right sensor (relating to facing the front of the task board) and the graph and digital readouts located on the bottom half are for the left sensor.

After each sensor is aligned, the transformation/scaling equations for voltage output versus displacement should be determined for both the X and Y axis of the sensor, of the plane perpendicular to the front of the sensor and located at a predefined origin (in front of the task board located at its center), shown in Figure 4-6. Determining the X axis scaling equation is accomplished by first locking the calibration unit's arm at 0°, then incrementally moving the target an inch at a time (while locking down the target each time) and recording the X voltage output from the sensor. The arm should then be locked at 180° and perform the same procedure. This information can then be loaded into a Cricket Graph spreadsheet and graphed as displacement versus output voltage. Then select the option for linear curve fit ("Simple Curve Fit") and a scaling equation for the X axis is displayed. The same procedure is used for determining the Y axis transformation equation when the arm is locked at 90°. The slope and intercept for both X and Y scaling equations are then entered into the front panel of the " 3-D P/F" instrument, shown in Figure 4-8. These new values for the equations are saved as default values by moving the mouse to each of these digital indicators, pushing down the command key and clicking the mouse button (presents a pop up window), and select the "Default << = Current Value" option. The " 3-D P/F" instrument program should then be saved.

The actual displacement values along both axes of each sensor, at the predefined origin, can be verified by using the "2-D Tracking Inst." program, shown in the Appendix, and calibration unit setup, shown in Figure 4-6. First, the scaling equations information that was entered into the "3-D P/F" program should be entered into the "2-D Tracking Inst." program, in the same manner as with the "Sensor Alignment Instrument" program, and then saved. With the "2-D Tracking Inst." program opened and operating, the target can be moved along the arm of the calibration unit and the position or motion of the target is displayed on the front panel. The operation of this program is similar to the operation of the "Sensor Alignment Instrument" program.

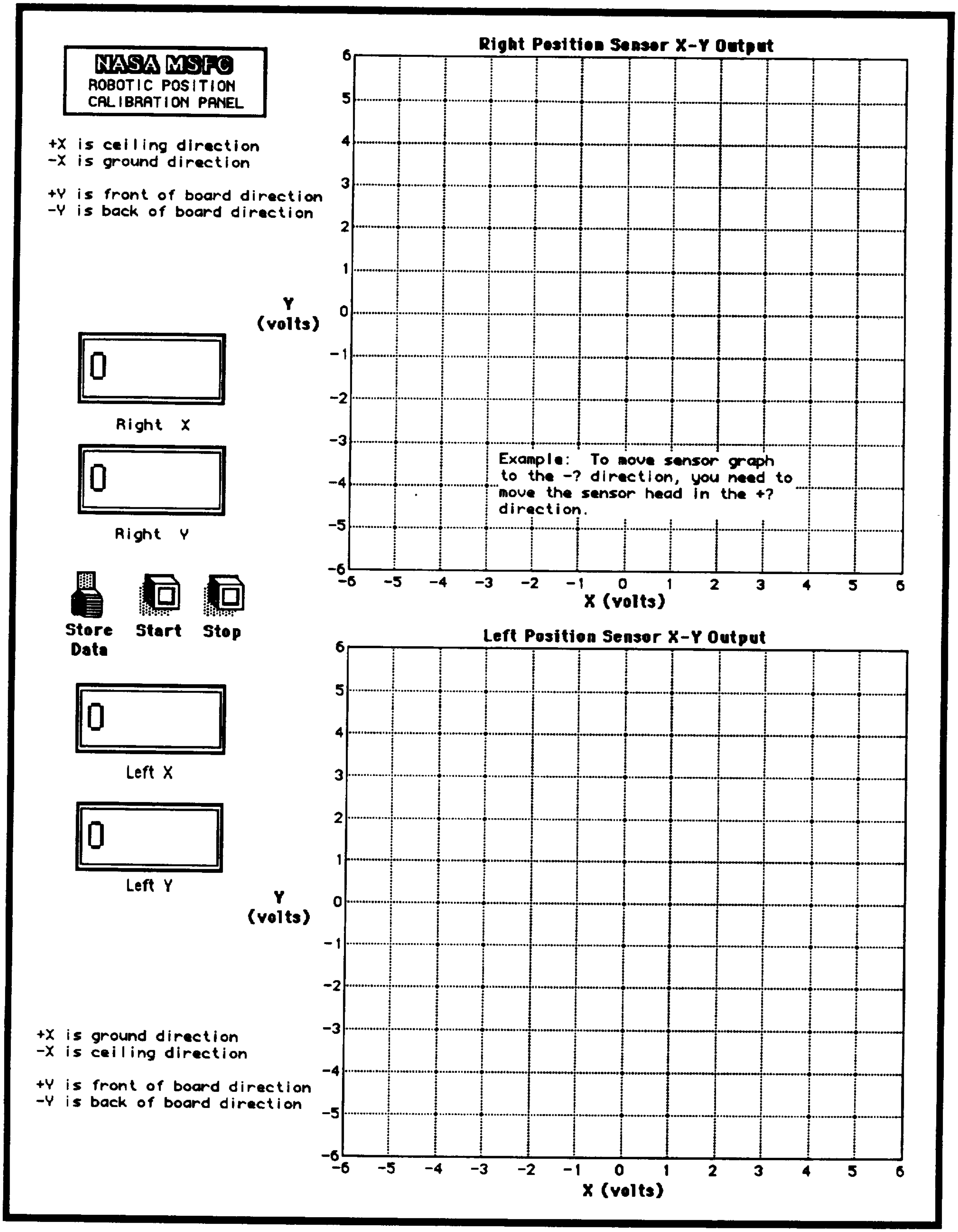


Figure 4-7 "Sensor Alignment/Scale Instrumentation" Front Panel

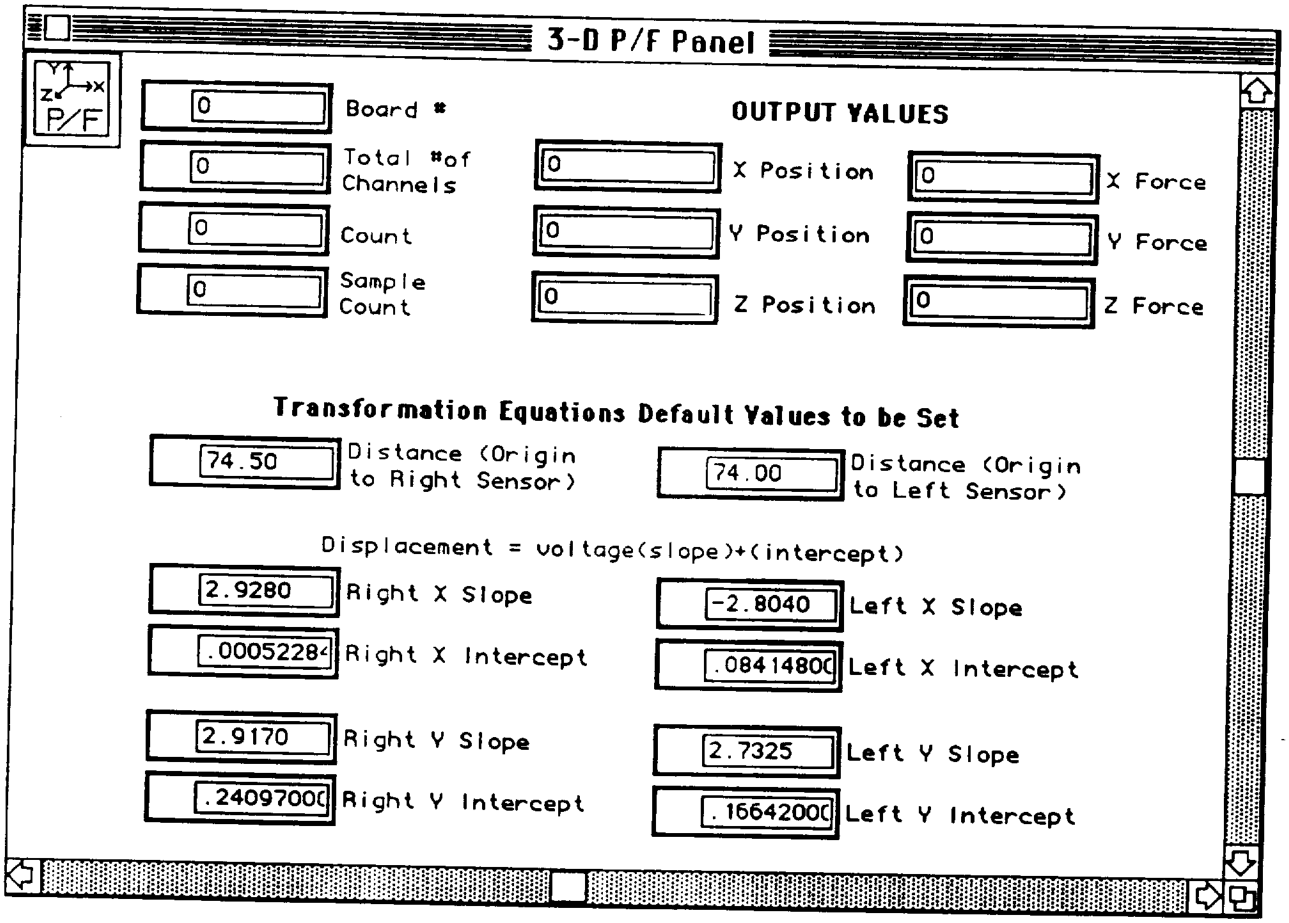


Figure 4-8 "3-D P/F" Program's Front Panel

The final step in calibrating the 3-D target tracking system is to determine the distance between the origin and each sensor and then entering that information into the "3-D P/F" program. Due to the inability of accurately measuring the distance between the origin and each sensor with a scale, the distance is calculated by determining the intersection of two lines passing through the +3 and -3 points on the X axis of each sensor. These lines are defined by polar coordinates in which the radius is held constant and the angle at each point in questioned can be determined. This can be accomplished by first bolting the calibration unit on the calibration panel, in the marked bolt holes, oriented with the degree scale on the calibration unit facing away from the front of the task board, as shown in Figure 4-9. This will allow the IR target, located on the arm of the calibration unit, to spin 360° about the center of a predefined origin. The target should be locked into place (at the 10", 11", 12", or 13" marks) which will allow for a constant radius. As shown in Figure 4-9, the calibration unit's arm should be rotated (with the target continually facing the sensor) and tightened down at both +3 and -3 points so that the angle of each point can be recorded. The angle of each point and the constant radius should then be entered into the program called "X-Y Intersection Point Inst.", shown in Figure 4-10. These points should be entered into the program with

reference to the location of the points shown in Figure 4-9. Once the program is executed, the distance between the origin and the sensor is displayed on the front panel of the program as "Y Intersection Point (in.)". (Note: The X intersection point displacement displayed on the front panel is accounted for with the scaling procedure described earlier.) This procedure should be repeated for each sensor. The displacement between the origin and each sensor should then be entered and saved in the "3-D P/F" program shown in Figure 4-8. This final step will conclude the calibration of the 3-D IR target tracking system.

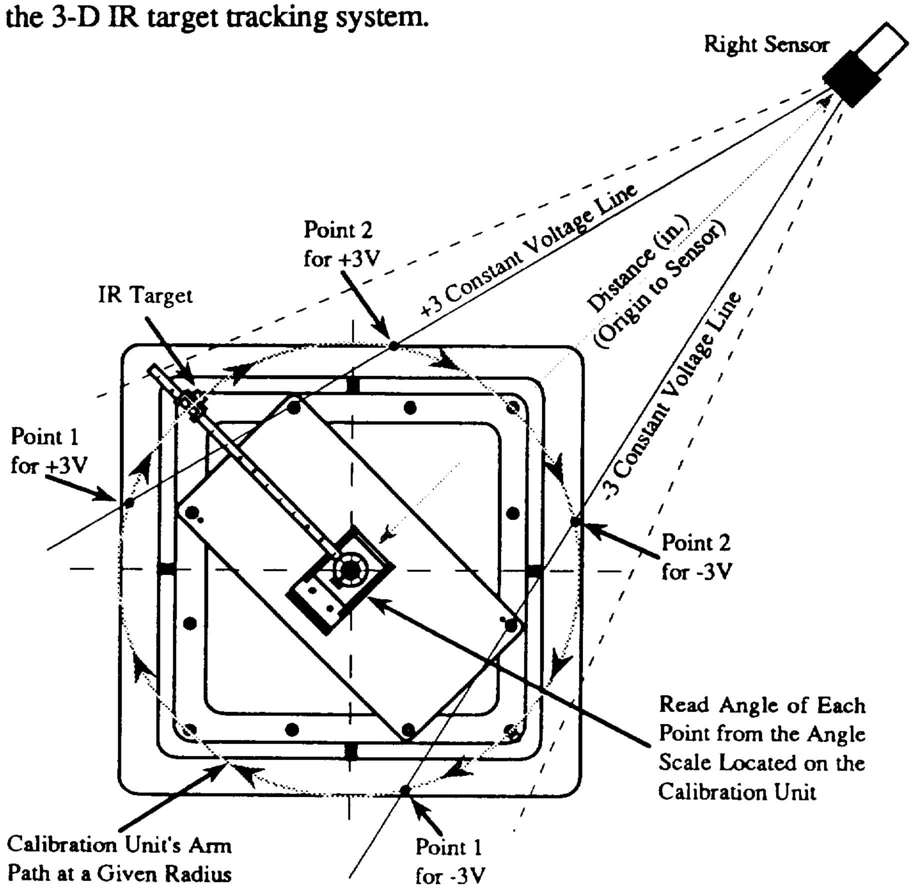


Figure 4-9 Determination of Distance from Origin to Right Sensor Using the Calibration Unit

The calibration of the target tracking system can be verified by running the "Main Task Board Program" shown in Figure 4-11. This program will take the 3-D position coordinates of the target and transform them to a common 3-D coordinate system with its origin located at the front center of the task board, +Z projecting out of the board, +Y projecting up vertically, and the +X projecting to the horizontal right of the board. The program also displays the 3-D forces imparted on the task board. This is the final version of the task board's software.

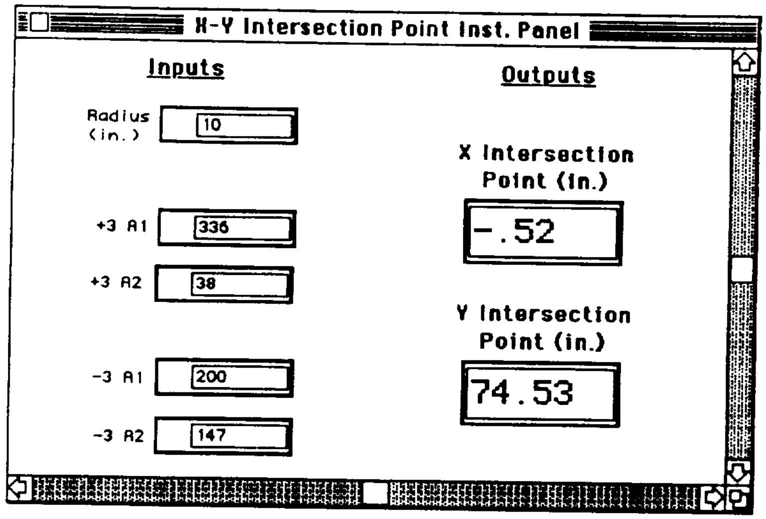


Figure 4-10 "X-Y Intersection Point Instrumentation" Front Panel

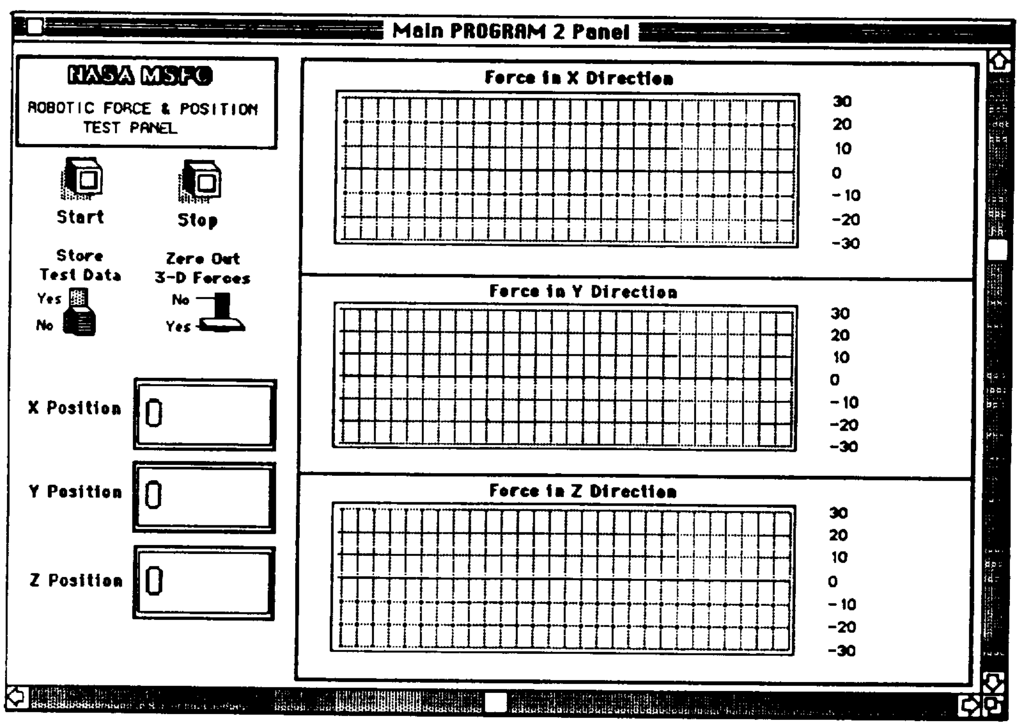


Figure 4-11 "Main Task Board Program" Front Panel

5.0 CONCLUSION

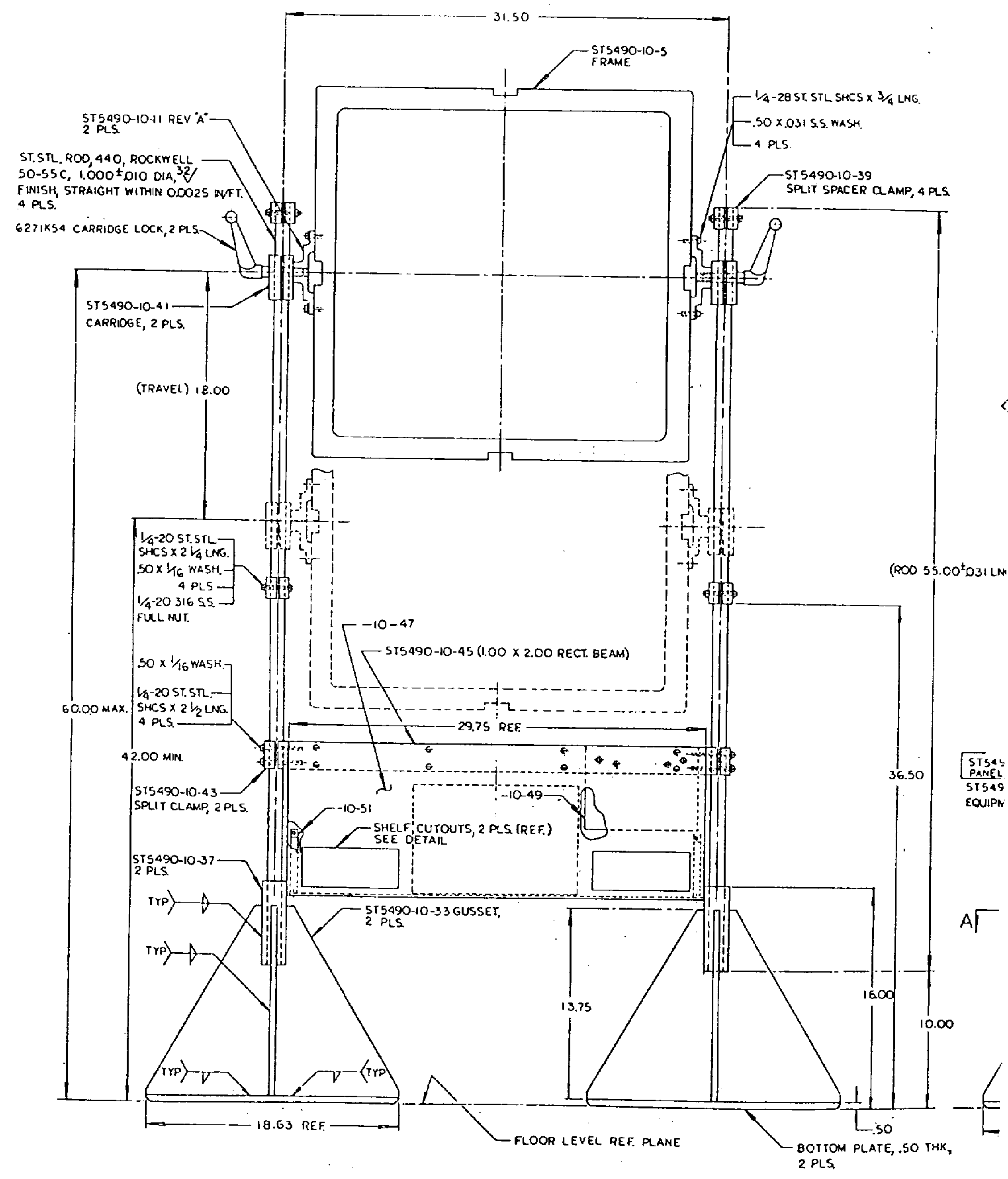
Currently there are no standards for laboratory comparisons of telerobotic systems. The instrumented task board design developed to evaluate the PFMA at MSFC could be useful for establishing a benchmark tool to evaluate telerobotic systems within the NASA centers. The data taken from the instrumented task board could be used as a departure point for technical discussions among NASA centers. The task board will support standardization and further define task analysis for telerobotics. Additional task sets can be added to the task board design to include a variety of tasks that include collision avoidance, adjustable inertia crank, lighting systems and dynamic situations.

APPENDIX

STAND DESIGN FINAL

ORIGINAL STAND DESIGN

FOLDOUT FRAME



ZONE	SYM	DESCRIPTION	DATE	APPROVAL
	A	REVISED ENTIRELY	7-25-90	

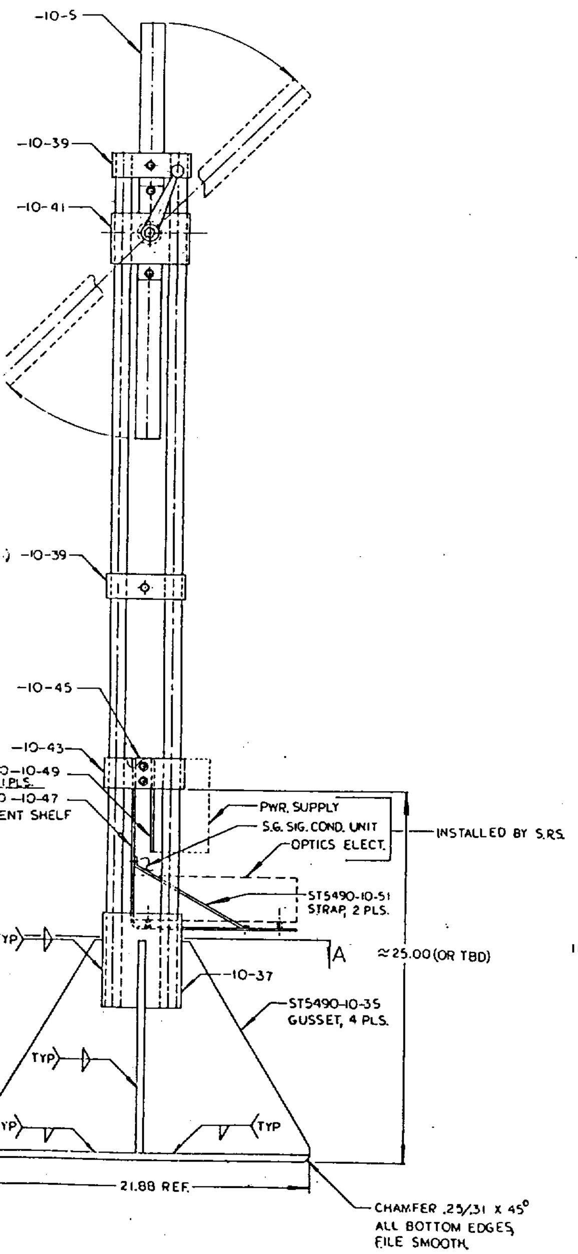
REVISIONS

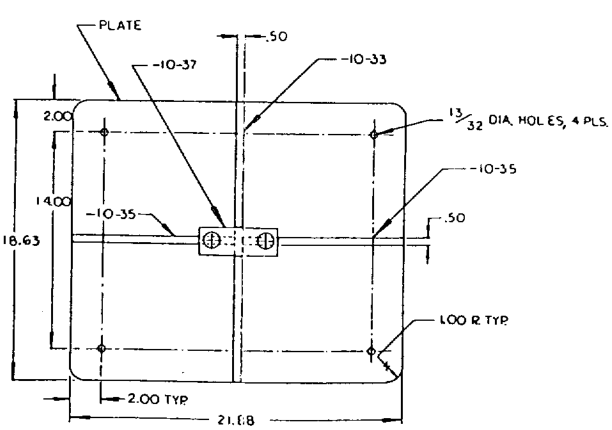
2.

FOLDOUT FRAME

NOTES

1. ALL PARTS SHALL BE FABRICATED FROM 6061-T6 ALUM ALLOY UNLESS OTHERWISE NOTED ON THE DRAWINGS AND SHALL BE FREE OF BURRS AND SHARP EDGES.

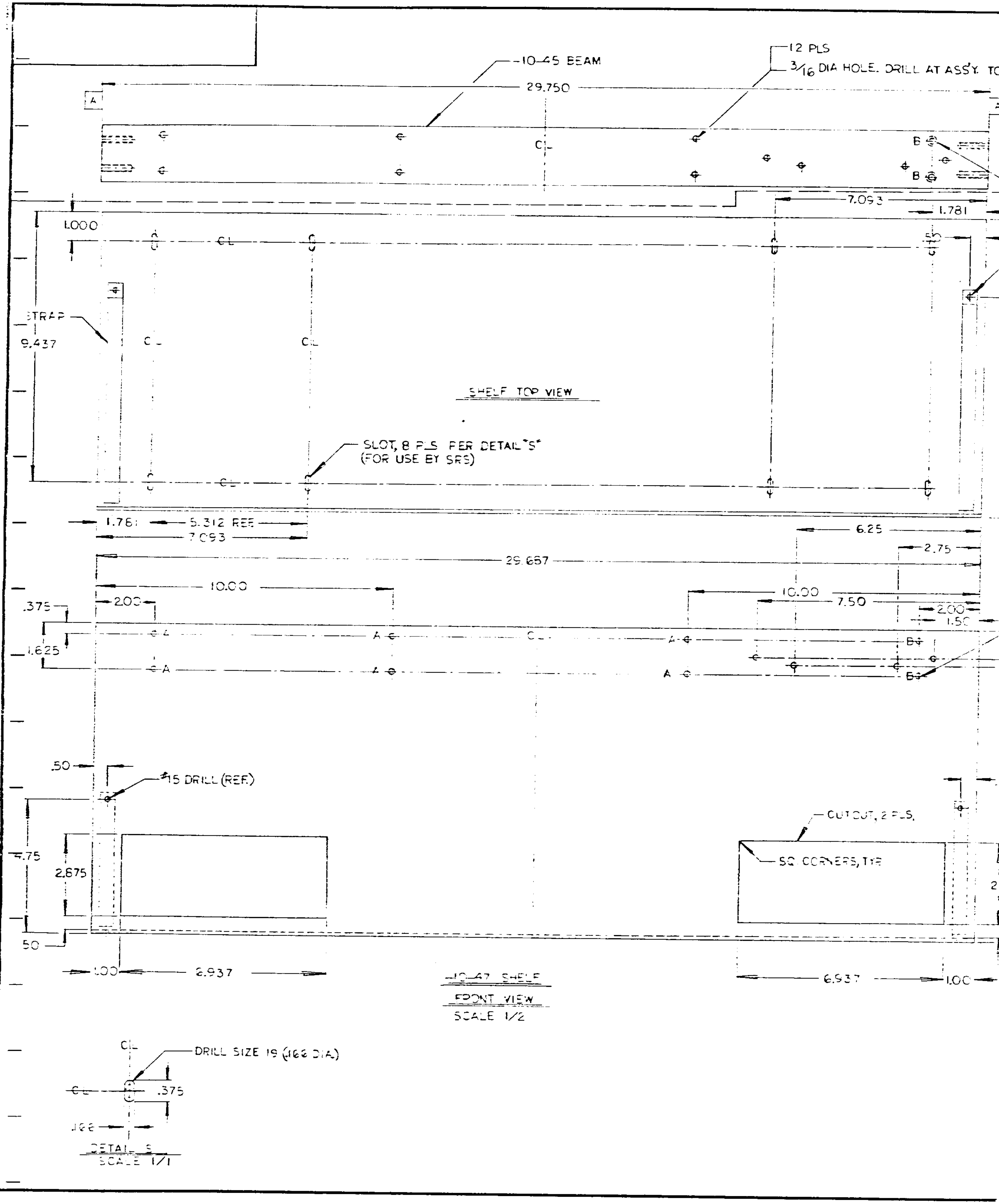




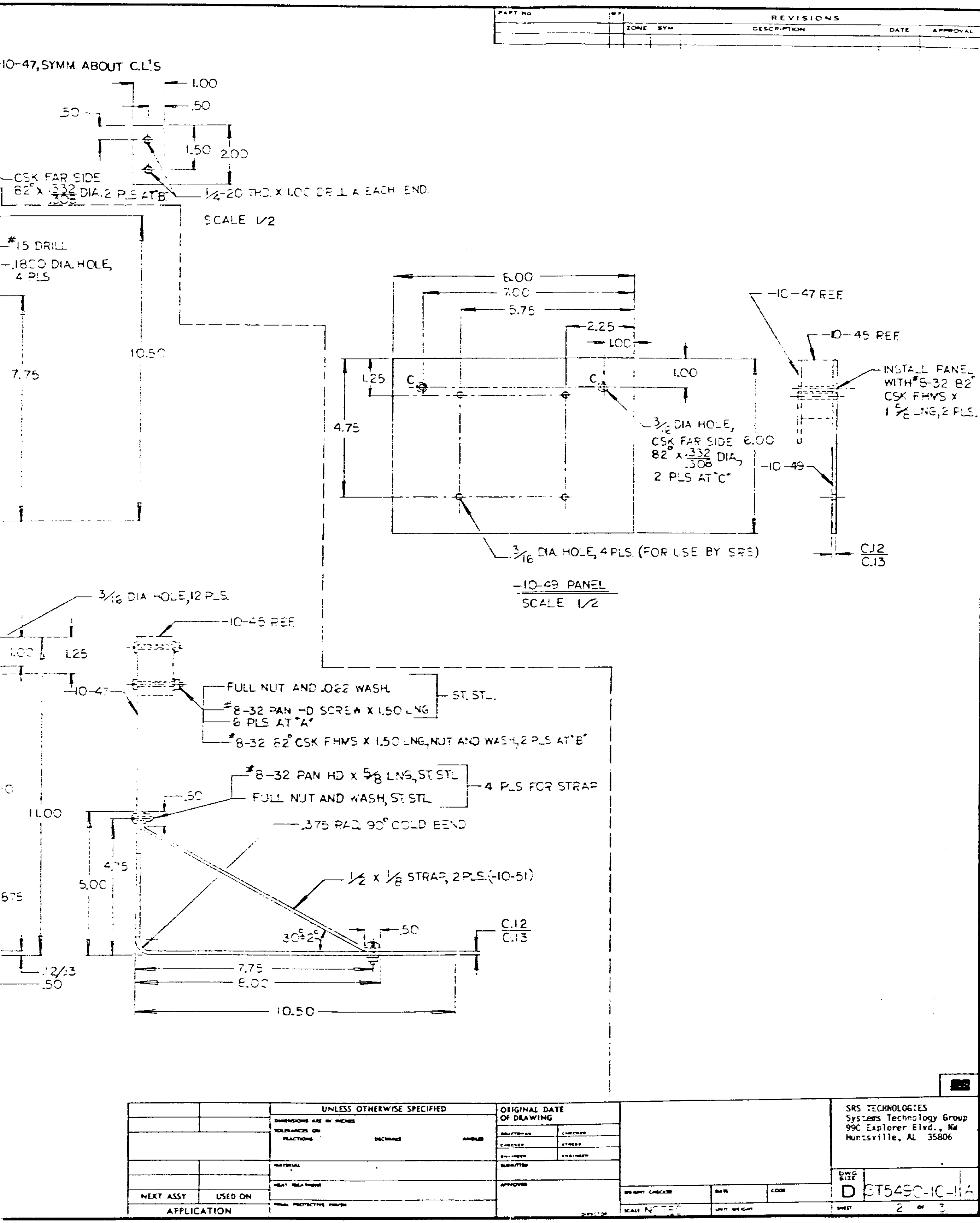
SECT. A-A (TYP 2 PLS)

REVISION A

NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS XX=±.02 XXX=±.010	ORIGINAL DATE OF DRAWING 7-25-90	MECH. ASS'Y. TORQUE PANEL SUPPORT FRAME	SRS TECHNOLOGIES Systems Technology Group 990 Explorer Blvd., NW Huntsville, AL 35806
APPLICATION		MATERIAL SEE NOTE 1.	DRAWN G.C. CHECKED P.G. ENGINEER P.G. G.C.		
		HEAT TREATMENT	SUBMITTED PAUL GIEROW		SIZE E DWG NO. ST5490-10-1 REV A
		FINAL PROTECTIVE FINISH PAINT PER S.R.S. SPEC.	APPROVED	SCALE 1/4" = 1" CODE 5Y959	SHEET 1 of 3



FOLDOUT FRAME



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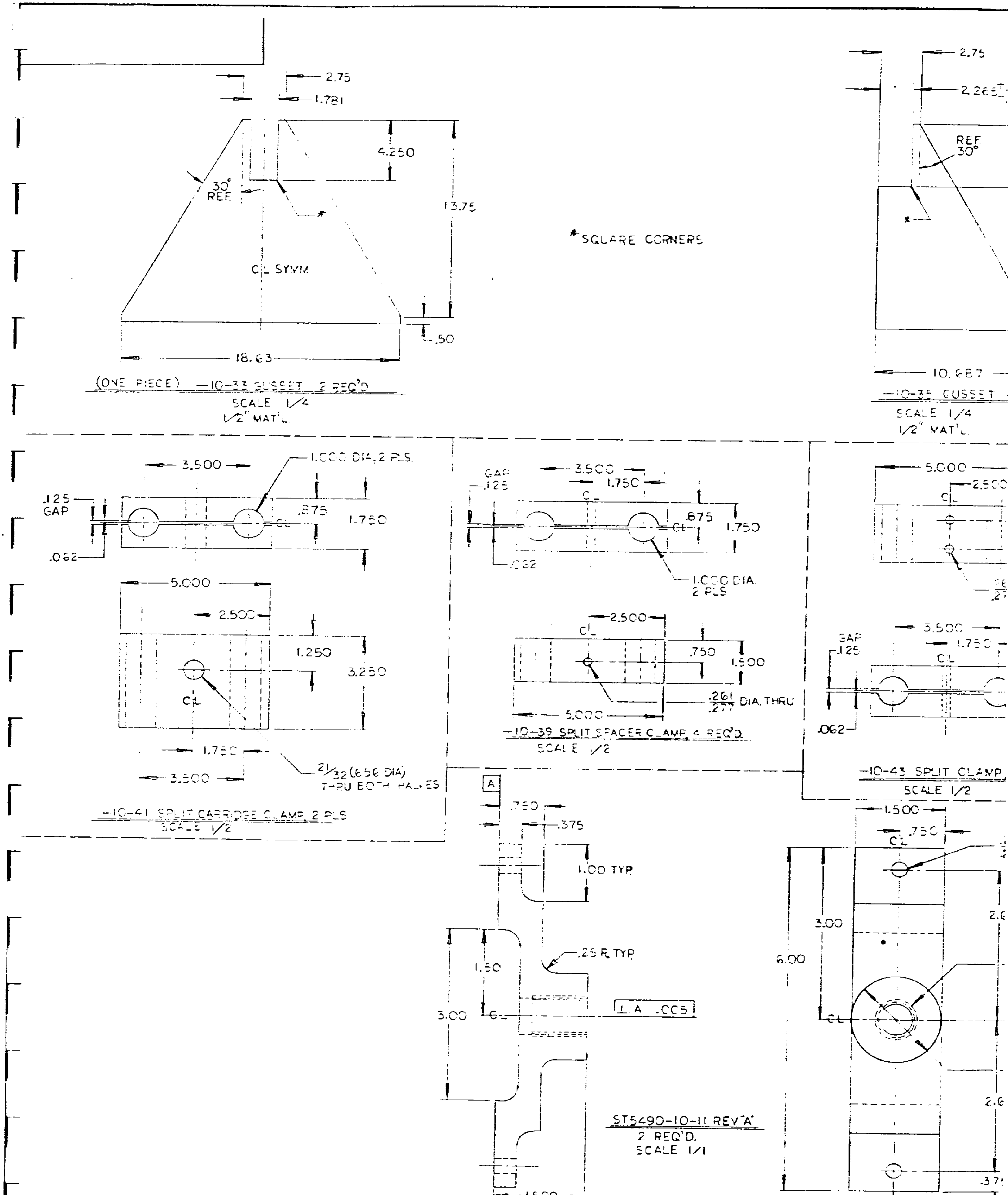

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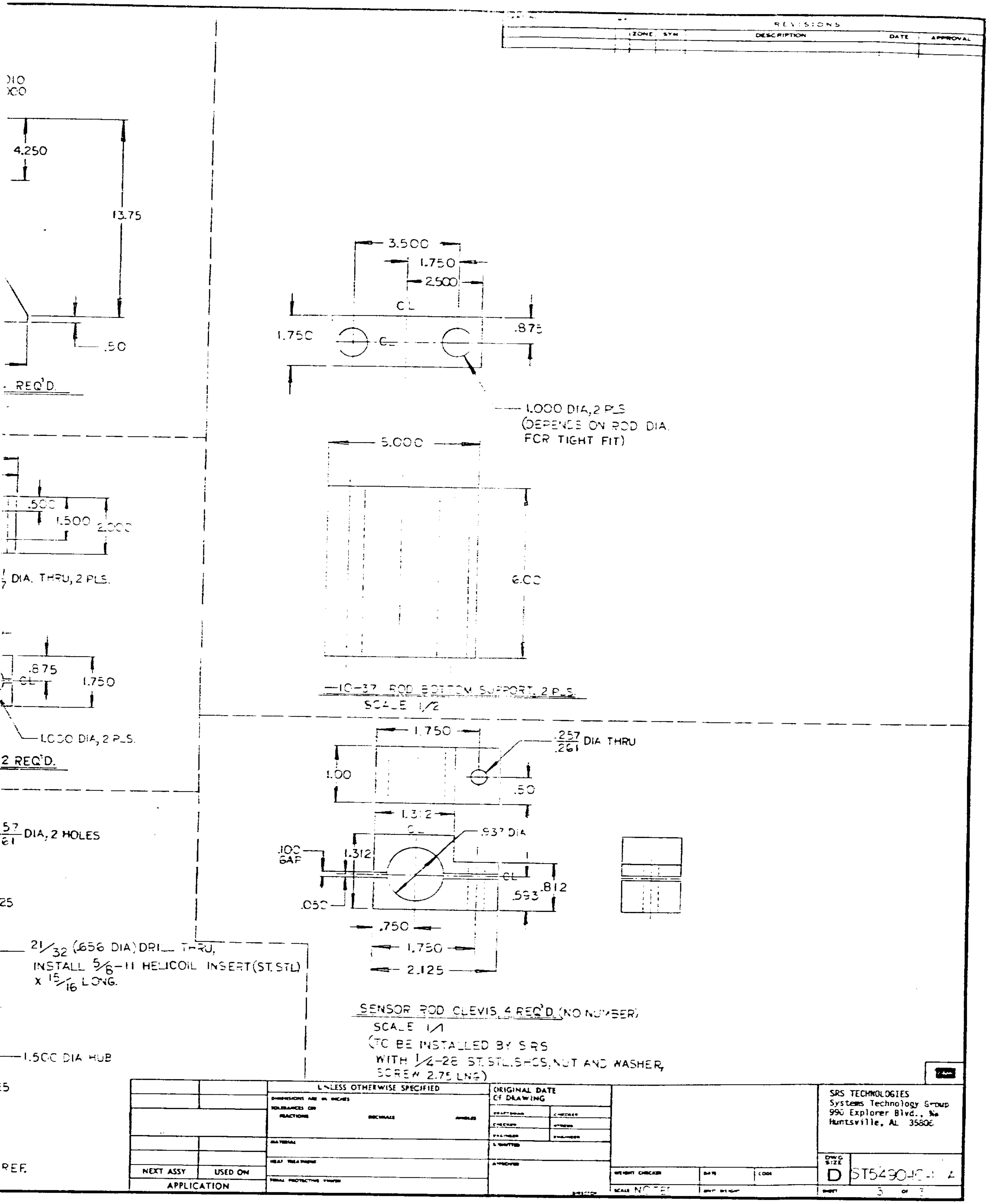

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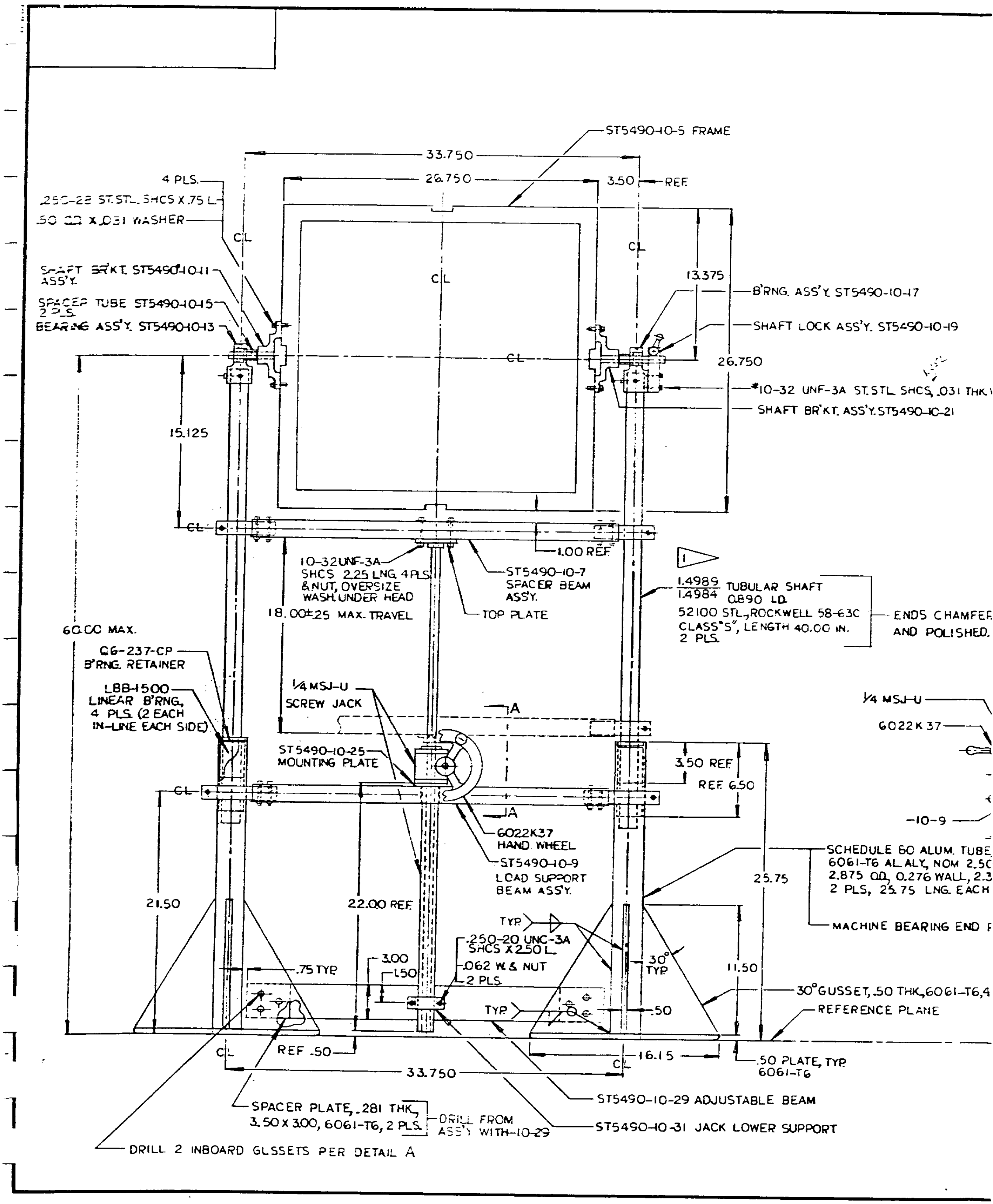
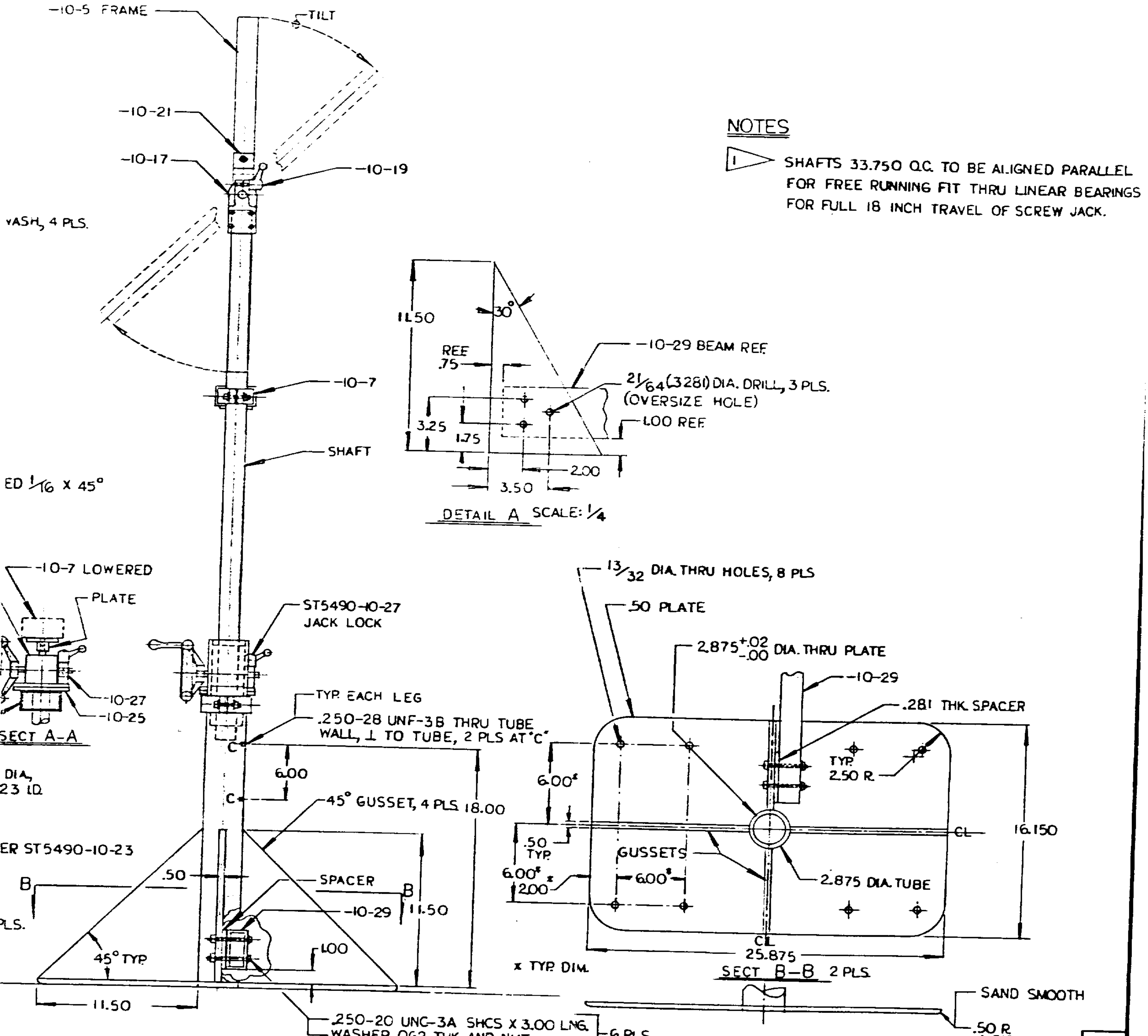


FOLDOUT FRAME

PART NO.		REVISIONS				
		ZONE	SYM	DESCRIPTION	DATE	APPROVAL

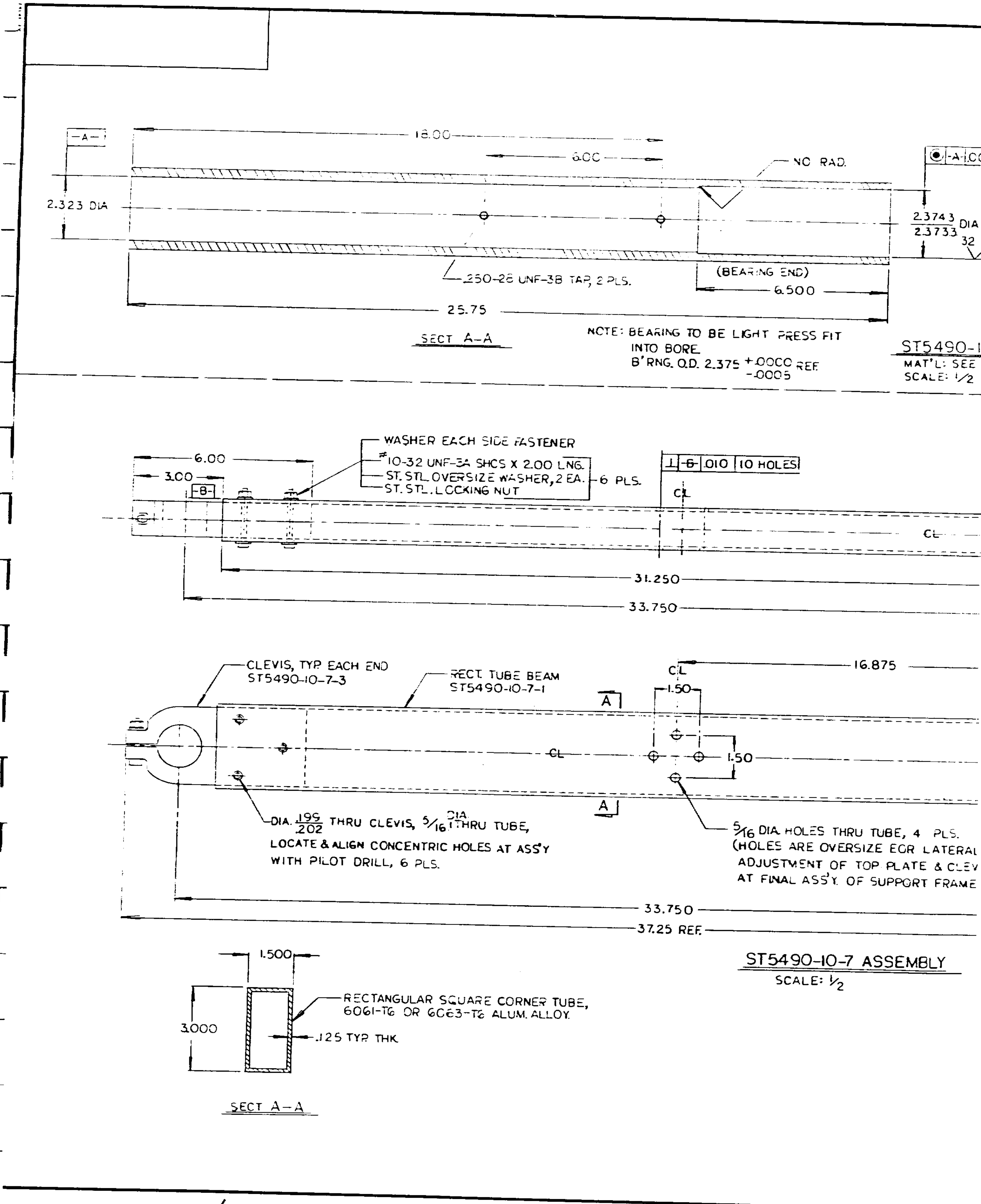
NOTES

1. SHAFTS 33.750 O.C. TO BE ALIGNED PARALLEL FOR FREE RUNNING FIT THRU LINEAR BEARINGS FOR FULL 18 INCH TRAVEL OF SCREW JACK.

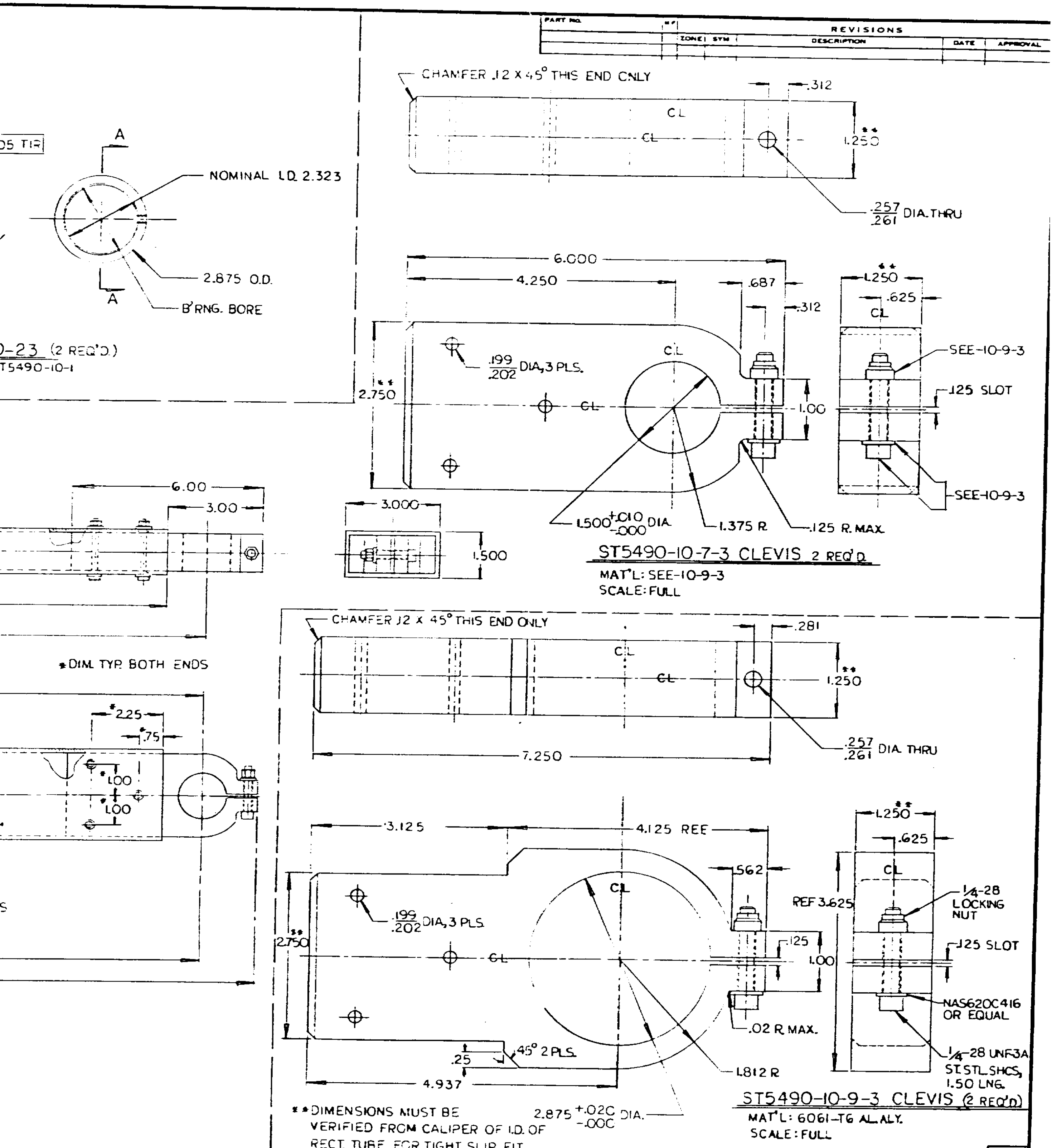


		UNLESS OTHERWISE SPECIFIED	ORIGINAL DATE OF DRAWING 6-18-90	MECHANICAL ASSEMBLY TORQUE PANEL SUPPORT FRAME	SRS TECHNOLOGIES Systems Technology Group 990 Explorer Blvd., NW Huntsville, AL 35806
[redacted]		.XX=±.02; .XXX=±.010	GC / PG / PG / GC		
		MATERIAL NOTED	P. GIEROW		
FINAL		HEAT TREATMENT N/A	APPROVED		SIZE D ST5490-10-1
NEXT ASSY	USED ON	FINAL PROTECTIVE FINISH SEE SPEC. PAINT ALUM PARTS		SCALE 1:5	SHEET 1 OF 1
APPLICATION					

FOLDOUT FRAME 2



FOLDOUT FRAME /



[redacted]

NEXT ASSY	USED ON
ST5490-10-1	

APPLICATION

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON: ALSO NOTED
.XX ± .02 .XXX ± .010
MATERIAL: NOTED

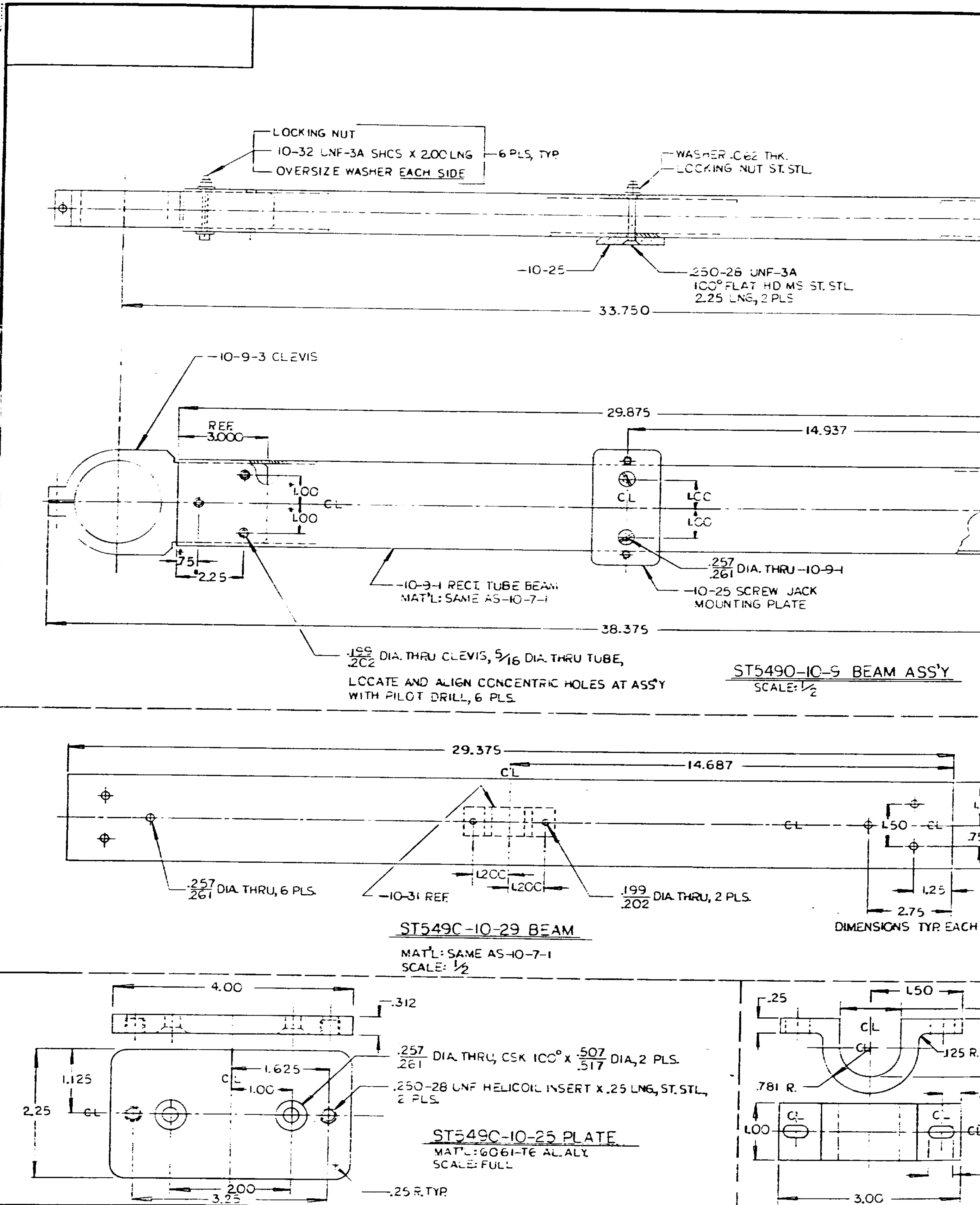
ORIGINAL DATE OF DRAWING: 6-20-90
DRAFTSMAN: GC
CHECKER: PG
ENGINEER: PG
ENGINEER: GC
SUBMITTED: PAUL GIEROW

DETAIL PARTS

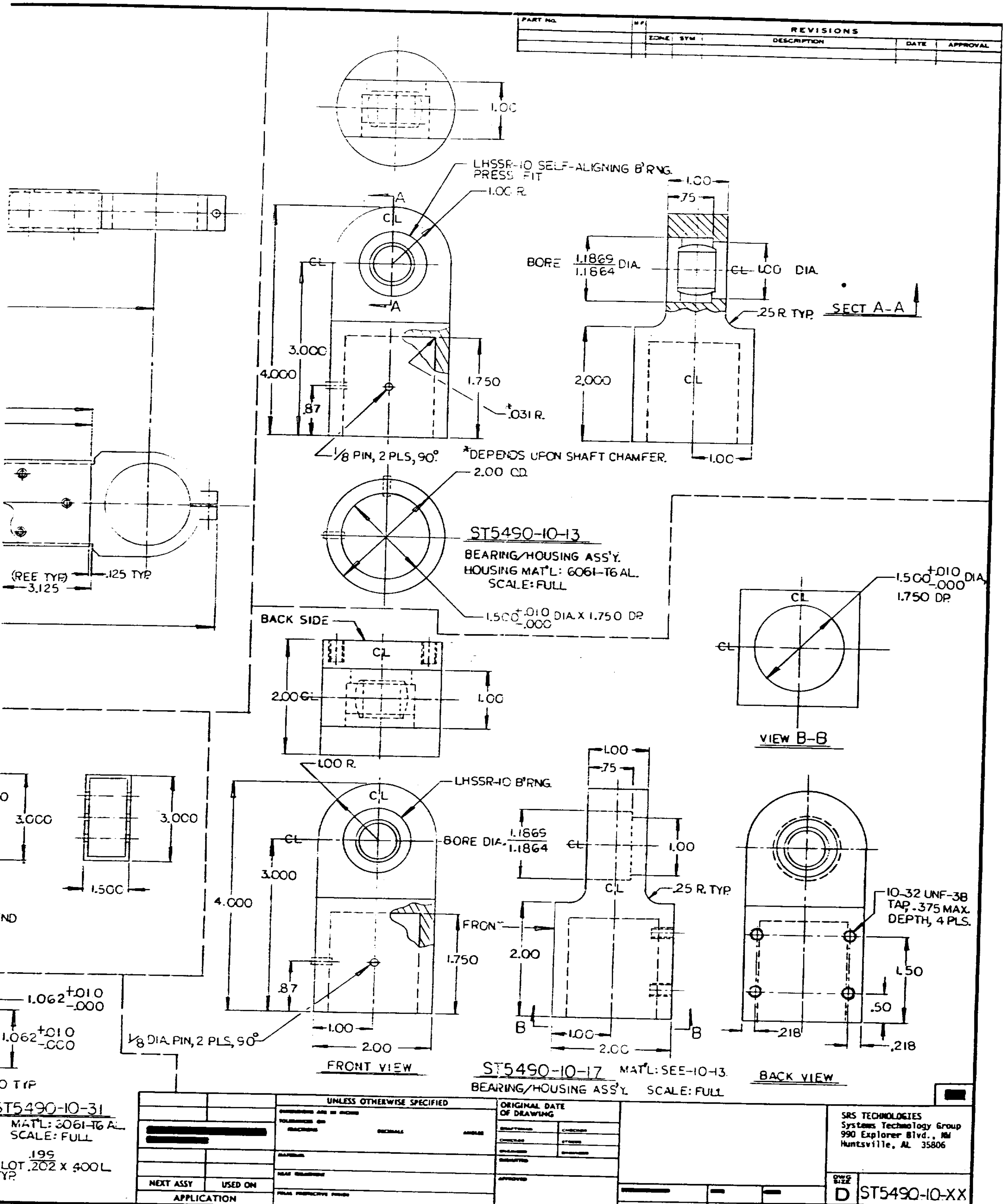
SRS TECHNOLOGIES
Systems Technology Group
990 Explorer Blvd., NW
Huntsville, AL 35806

DWG SIZE: D ST5490-10-XX
SCALE: NOTED
SHEET 1 OF 3

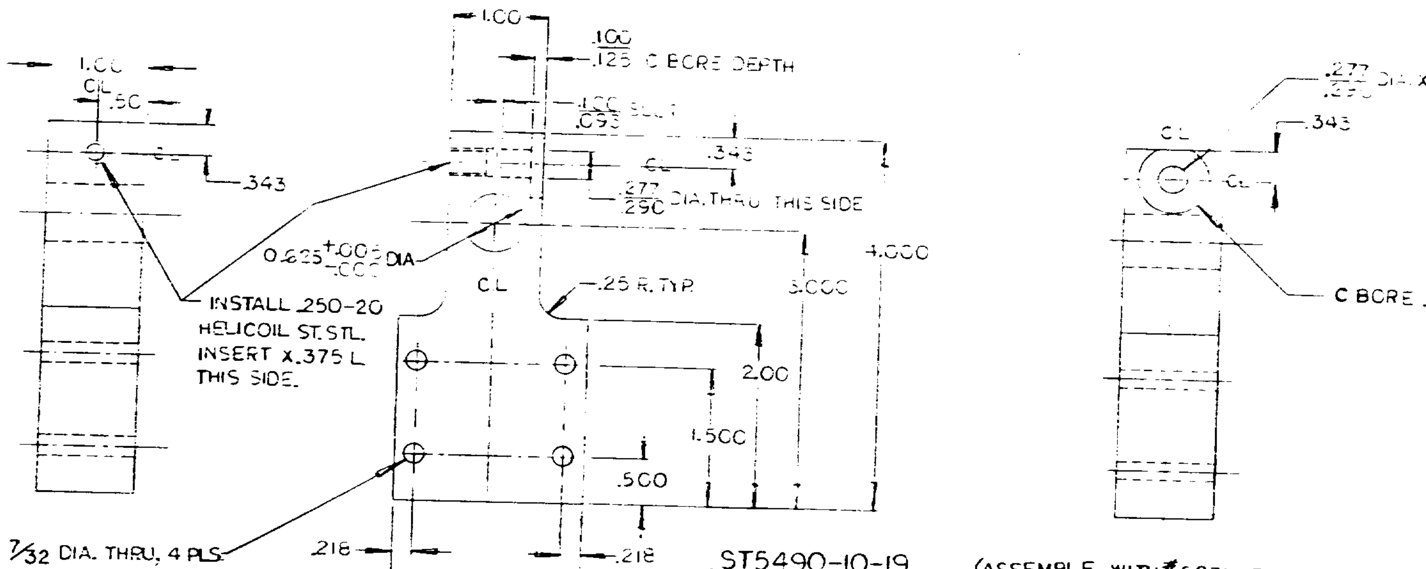
FOLDOUT FRAME 2



FOLDOUT FRAME /



FOLDOUT FRAME 2

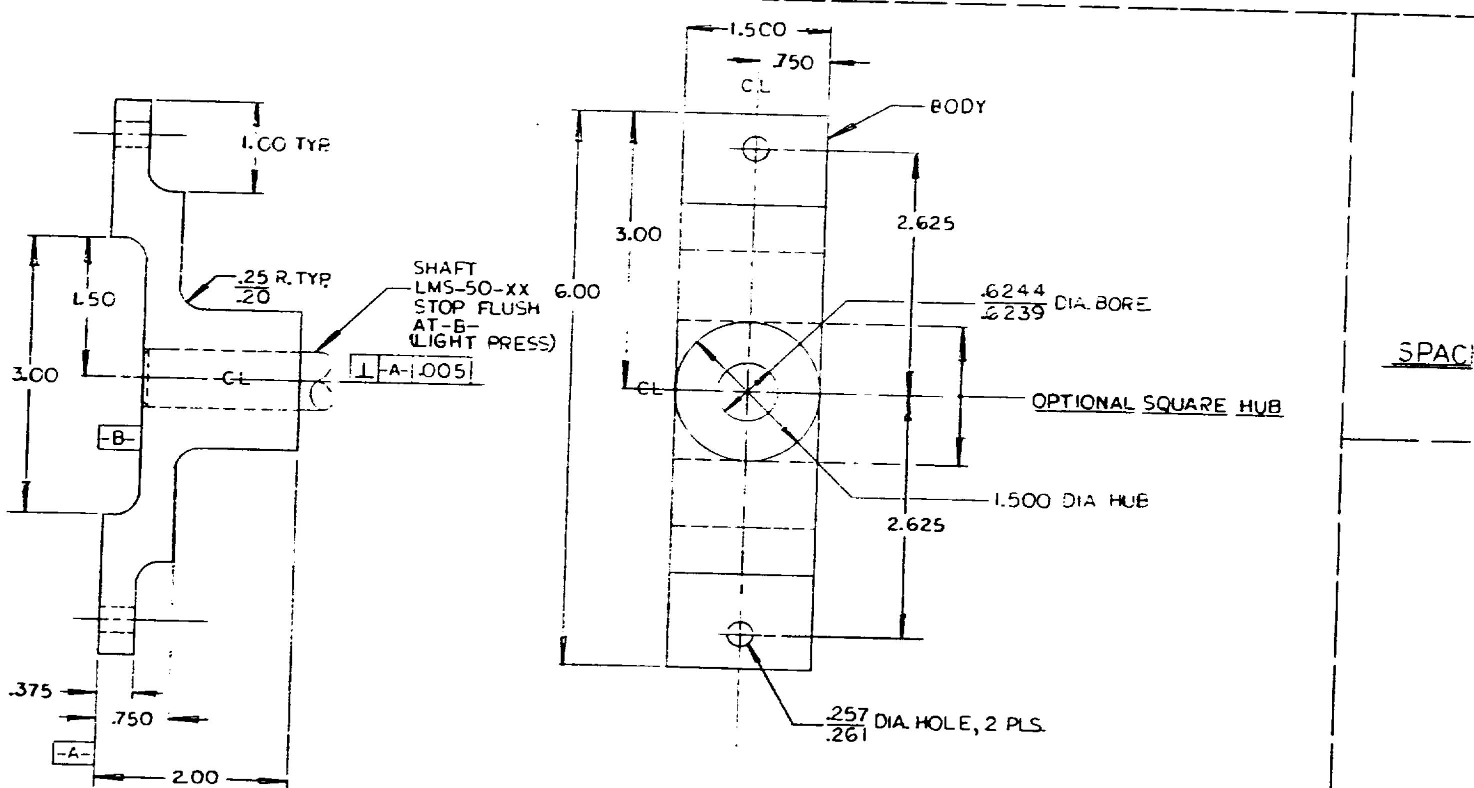


ST5490-10-19 (ASSEMBLE WITH #6271K13 CLAMPING HAN

SHAFT LOCK BODY

MAT'L: 6061-T6 AL. ALY.

SCALE: FULL



ST5490-10-11 & -10-21

-10-11 HAS 4.00 SHAFT L'NGTH. (LMS-50-4.00)

-10-21 HAS 4.50 SHAFT L'NGTH. (LMS-50-4.50)

BODY MAT'L: 6061-T6 AL. ALY.

SCALE: FULL

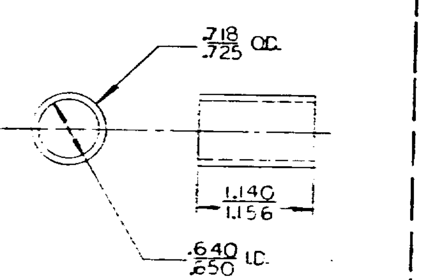
FOLDOUT FRAME 1.

PART NO.		REVISIONS			
	ZONE	SYM	DESCRIPTION	DATE	APPROVAL

325 DP

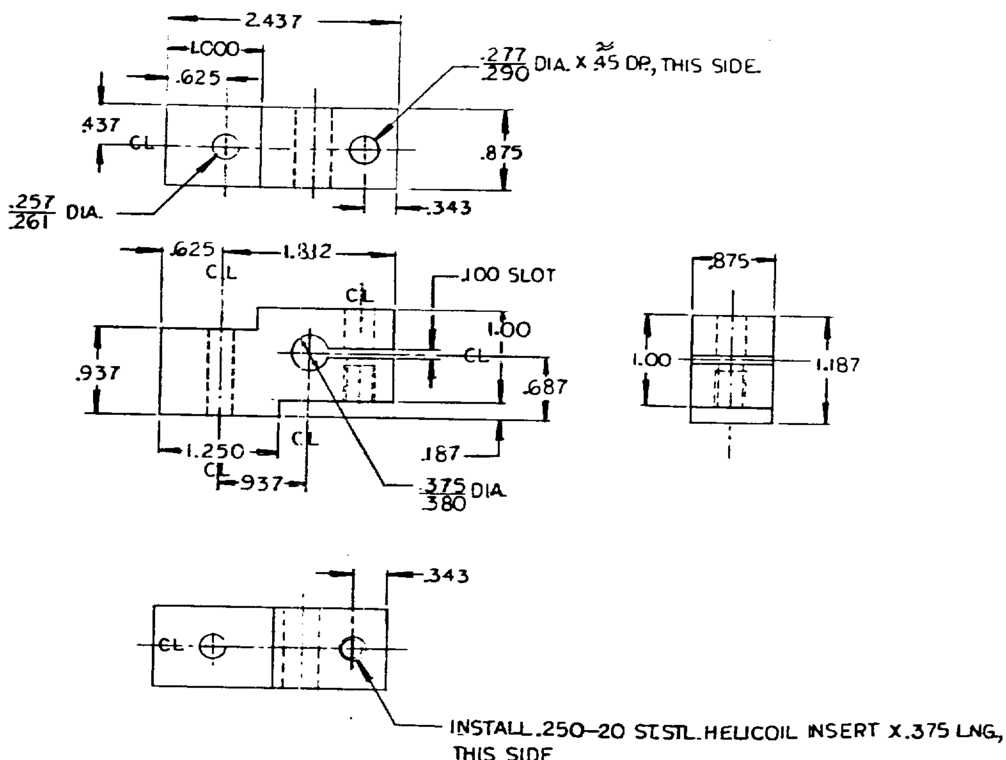
34 x .130/.125 DP

LE)



R, ST5490-10-15 2 REQ'D.

MAT'L: BRONZE, ALUM, OR ST. STL.
SCALE: FULL



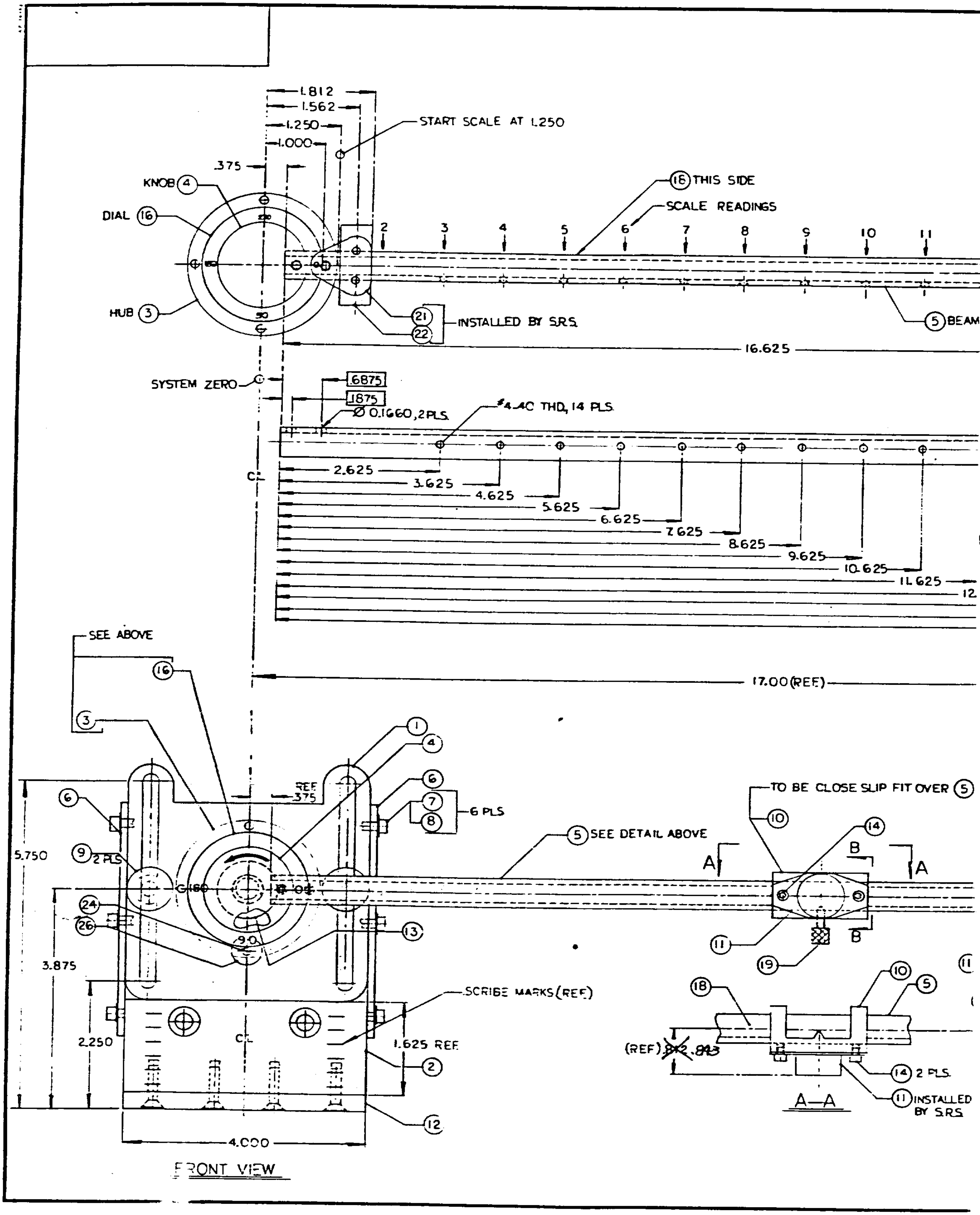
ST5490-10-27 JACK LOCK (INSTALL 6271K13 HANDLE)

MAT'L: 6061-T6 AL. ALY.
SCALE: FULL
THIS PART MATES WITH SCREW JACK & IS FASTENED TO
THE-10-25 PLATE WITH A .250-28 SHCS X 1.25 LNG., PLUS .031 THK. WASHER

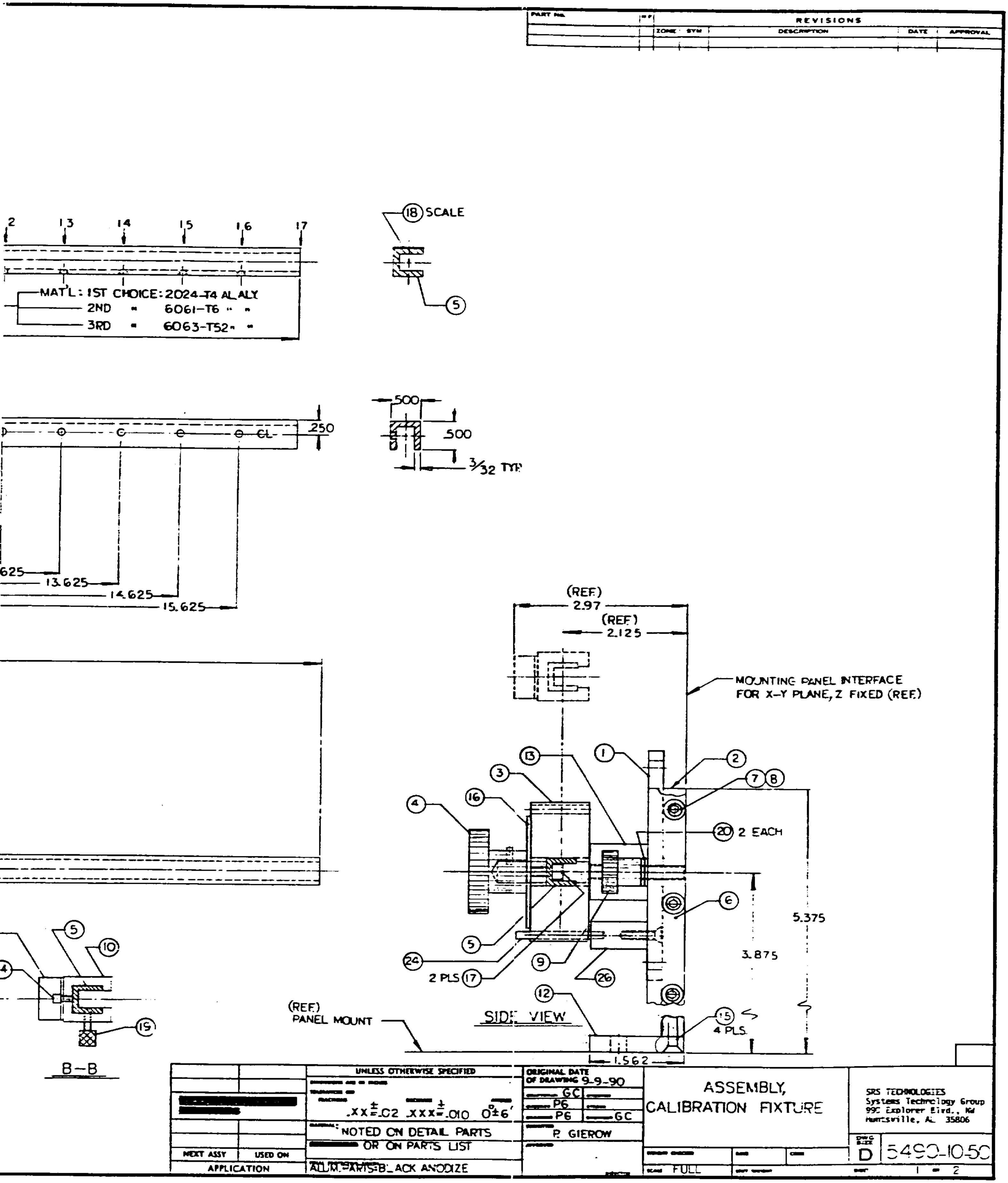
APPLICATION				DO NOT SCALE DRAWING	SIGNATURE	DATE	SRS TECHNOLOGIES [redacted]
THIS ITEM IS USED ON SUBASSEMBLIES				UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	DRAWN BY		TITLE
DRAWING NO	PER ASSY	NO. OF ASSYS	TOTAL	.XX = .XXXX =	PROJECT ENG'R		
				.XXX = ANGLES =	ENG'R		
				MATERIAL	APPROVED BY		
				TREATMENT	APPROVED BY		SIZE D · CODE IDENT. NO. 9V959 · DWG. NO. ST5490-10-XX · REV
FINAL ASSEMBLY ST5490-10-1			TOTAL REQ'D. 1	FINISH	SUBMITTED BY		
					DIRECTOR		SCALE · SHEET 3 OF 3

FOLDOUT FRAME 2

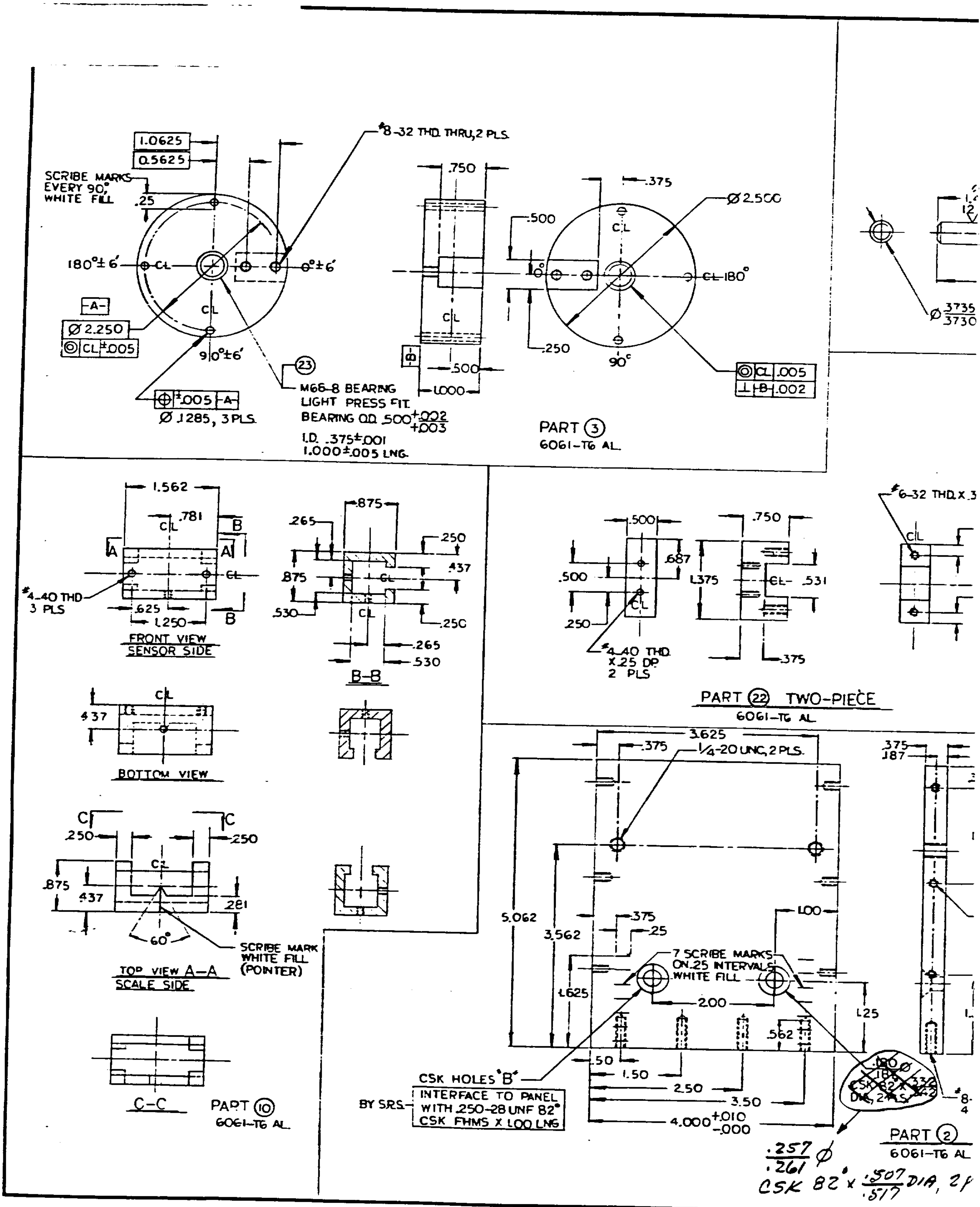
OPTICAL CALIBRATION DESIGN



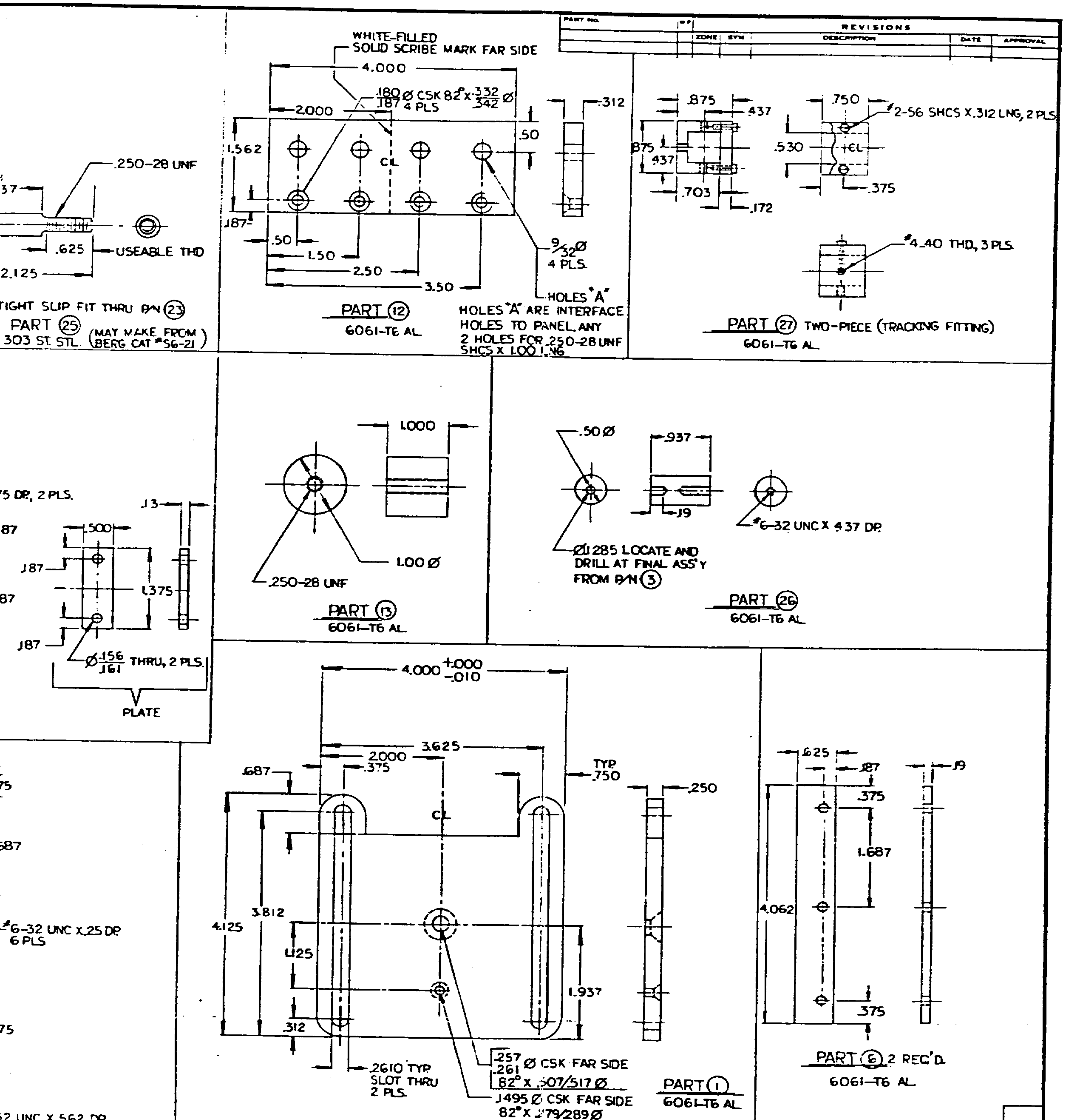
FOLDOUT FRAME



FOLDOUT FRAME 2



FOLDOUT FRAME



[redacted]	UNLESS OTHERWISE SPECIFIED	ORIGINAL DATE OF DRAWING
	6061-T6 AL. ALY.	
NEXT ASSY / USED ON	WHITE FILL SCRIBE MARKS	
APPLICATION	BLK. ANODIZE	

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Systems Technology Group
990 Explorer Blvd., NW
Huntsville, AL 35806

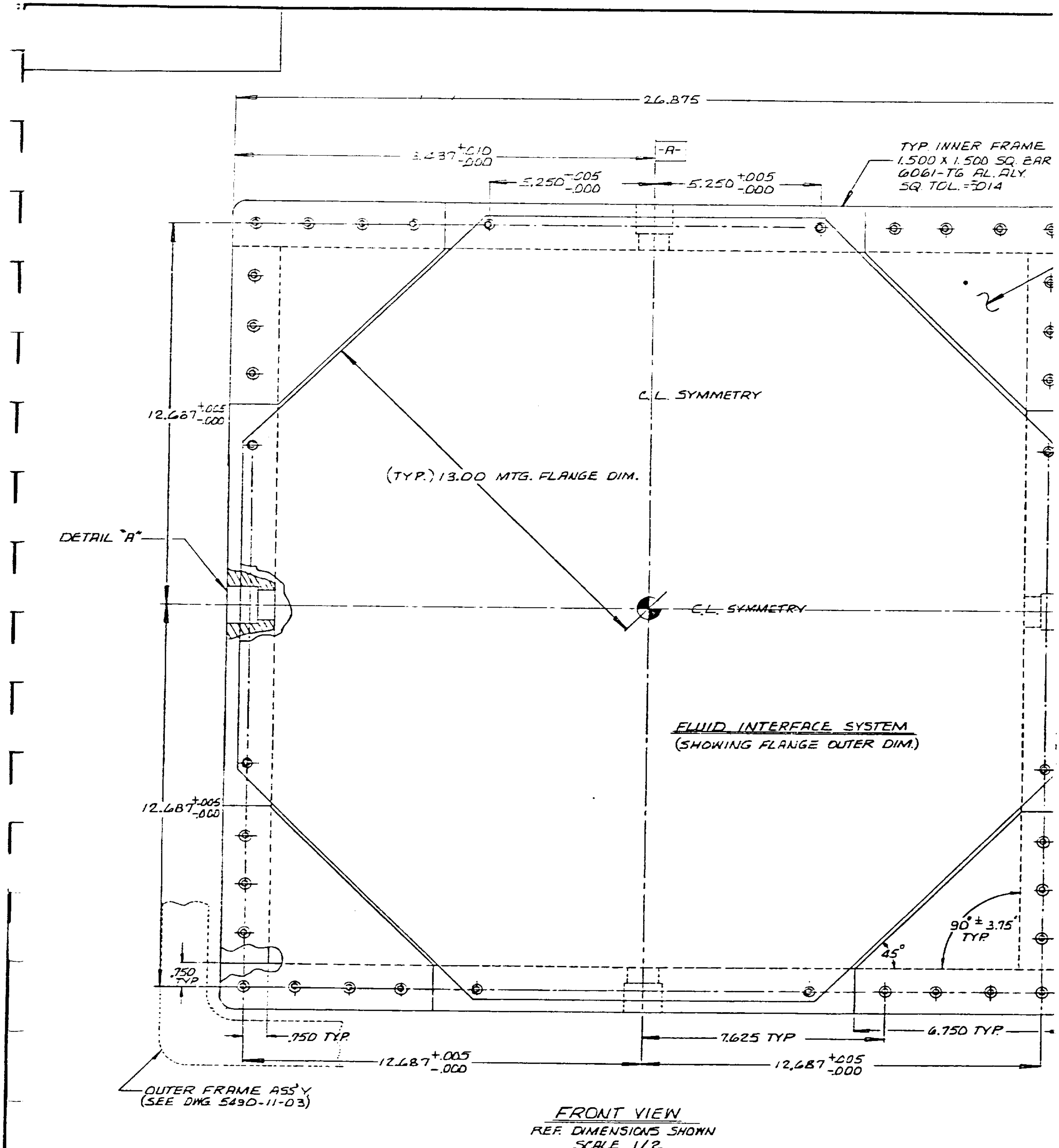
SIZE D 5490-10-50

SCALE FULL

SHEET 2 of 2

2.

ADDITIONAL TASK BOARD DESIGN

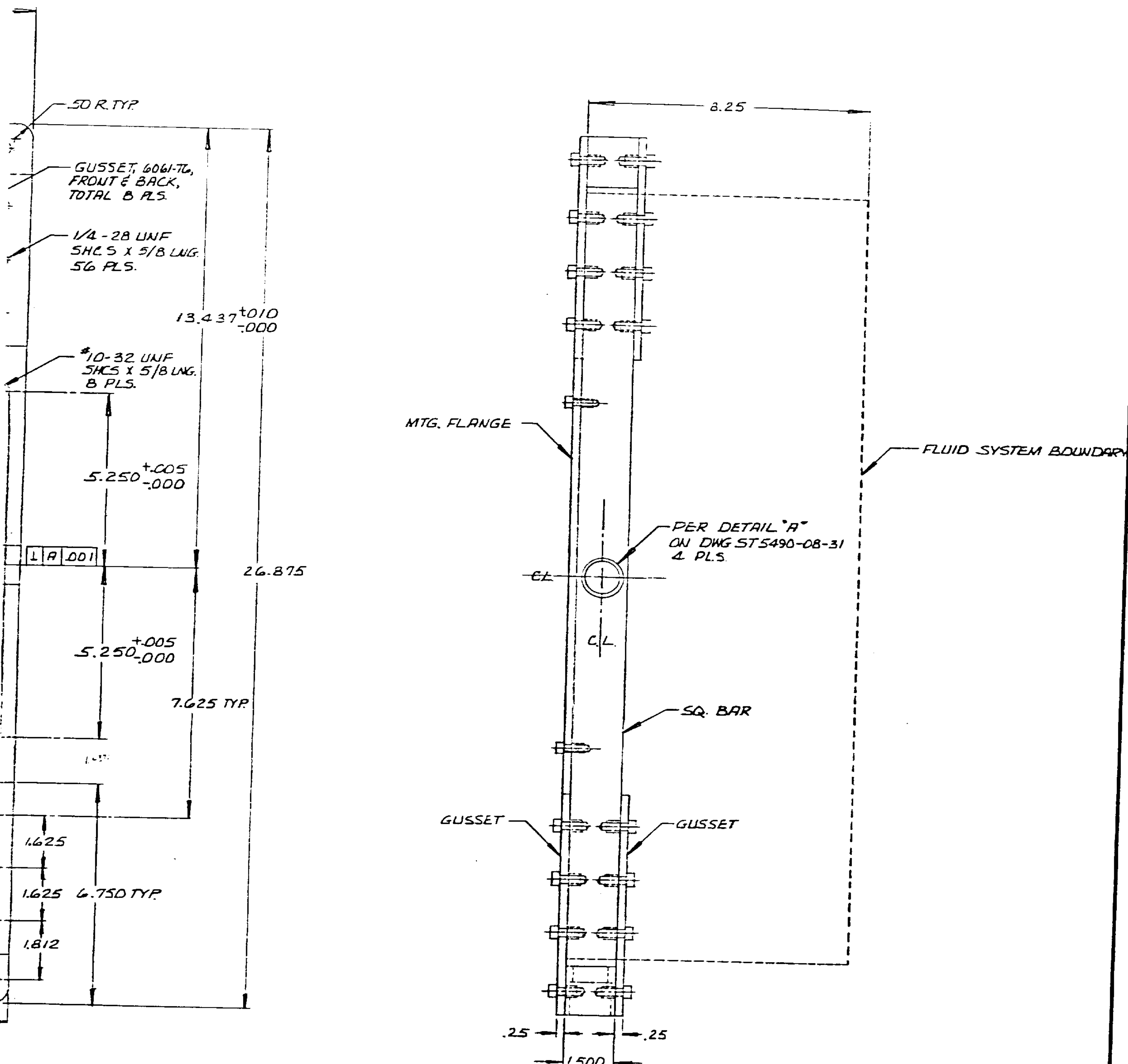


FRONT VIEW
REF. DIMENSIONS SHOWN
SCALE 1/2

FOLDOUT FRAME

PART NO.	REV	ZONE	SYM	DESCRIPTION	DATE	APPROVAL

REVISIONS



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON: ALSO NOTED
DECIMALS: .XX ±.02 .XXX ±.010 ANGLES: 0° ±.75
MATERIAL: 6061-T6 AL. ALY.
HEAT TREATMENT: N/A
FINAL PROTECTIVE FINISH: ALODINE & PAINT
ALUM. PARTS

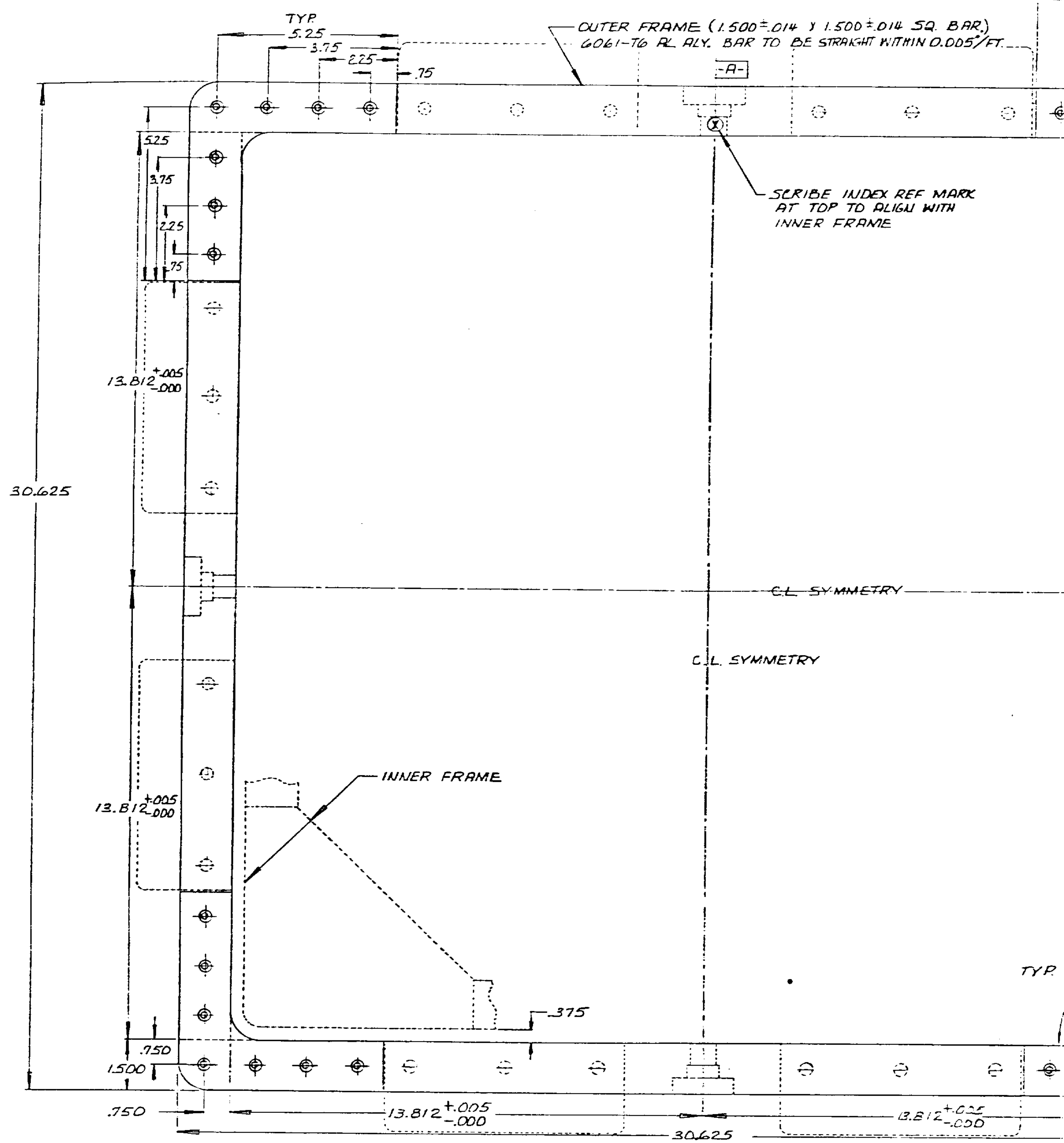
ORIGINAL DATE OF DRAWING: 10-5-90
DRAFTSMAN: G.C.
CHECKED: P.G.
STRESS: J.M.
CHANGED: P.G.
ENGINEER: G.C.
SUBMITTED: PAUL GIEROW
APPROVED:

INNER FRAME ASSEMBLY
FLUID INTERFACE SYSTEM

SRS TECHNOLOGIES
Systems Technology Group
990 Explorer Blvd., NW
Huntsville, AL 35806

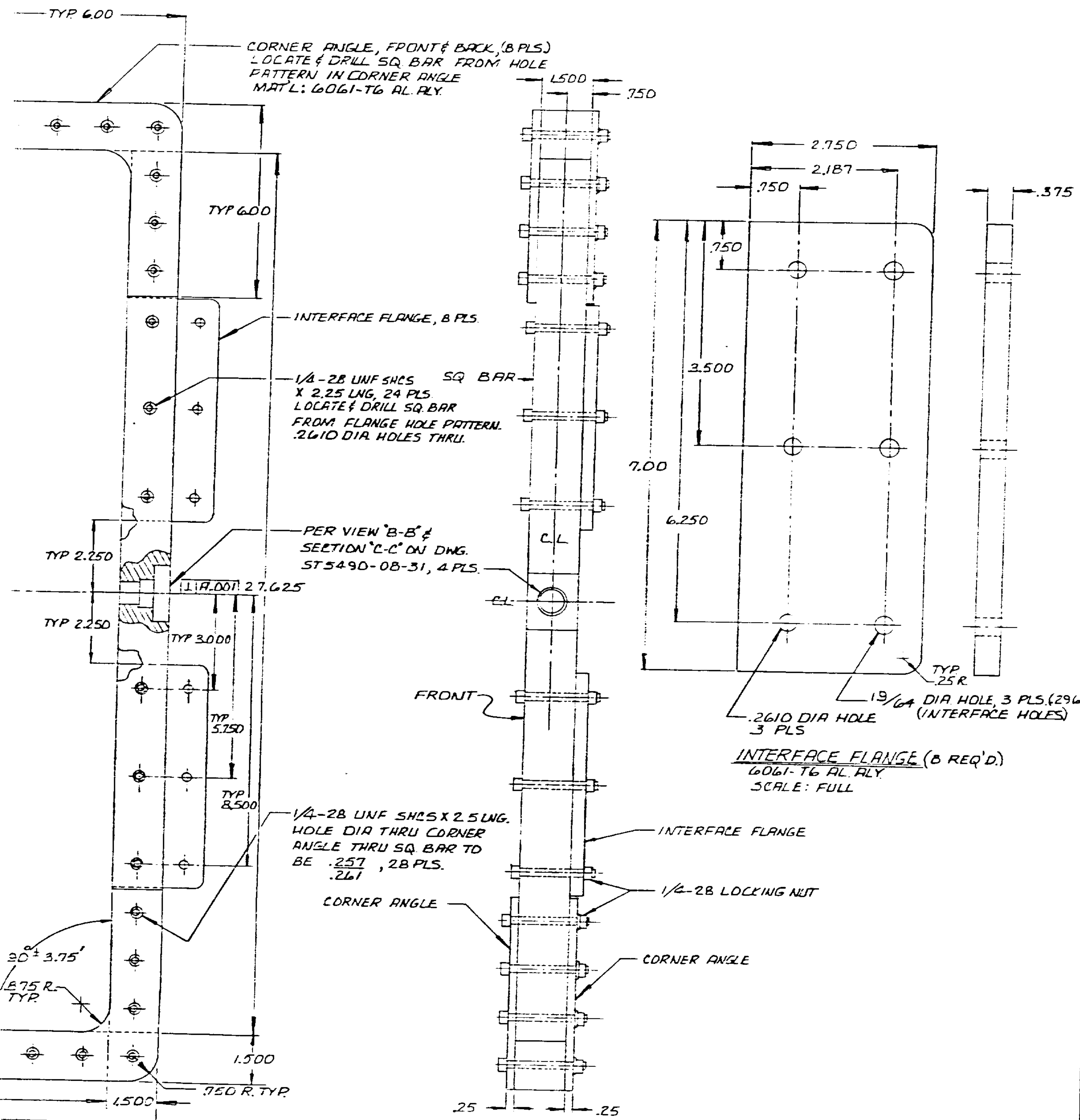
DWG SIZE: D
5490-11-02
SCALE: 1/2
UNIT WEIGHT: 30.0 LBS
SHEET 1 OF 1

FOLDOUT FRAME 2.



OUTER FRAME
FRONT VIEW
SCALE 1/2

FOLDOUT FRAME /



REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES (SOME DIM. NOTED)

TOLERANCES ON: DECIMALS .XX ±.02, .XXX ±0.010; ANGLES 0° ±3.75'

MATERIAL: NOTED

HEAT TREATMENT: N/A

FINAL PROTECTIVE FINISH: ALL PARTS ALODINE & PAINT

NEXT ASSY | USED ON

APPLICATION

ORIGINAL DATE OF DRAWING: 10-8-90

DRAFTSMAN: GC | CHECKER:

CHECKER: PG | DESIGN: JM

ENGINEER: PG | ENGINEER: GC

SUBMITTED: PAUL GIEROW

APPROVED:

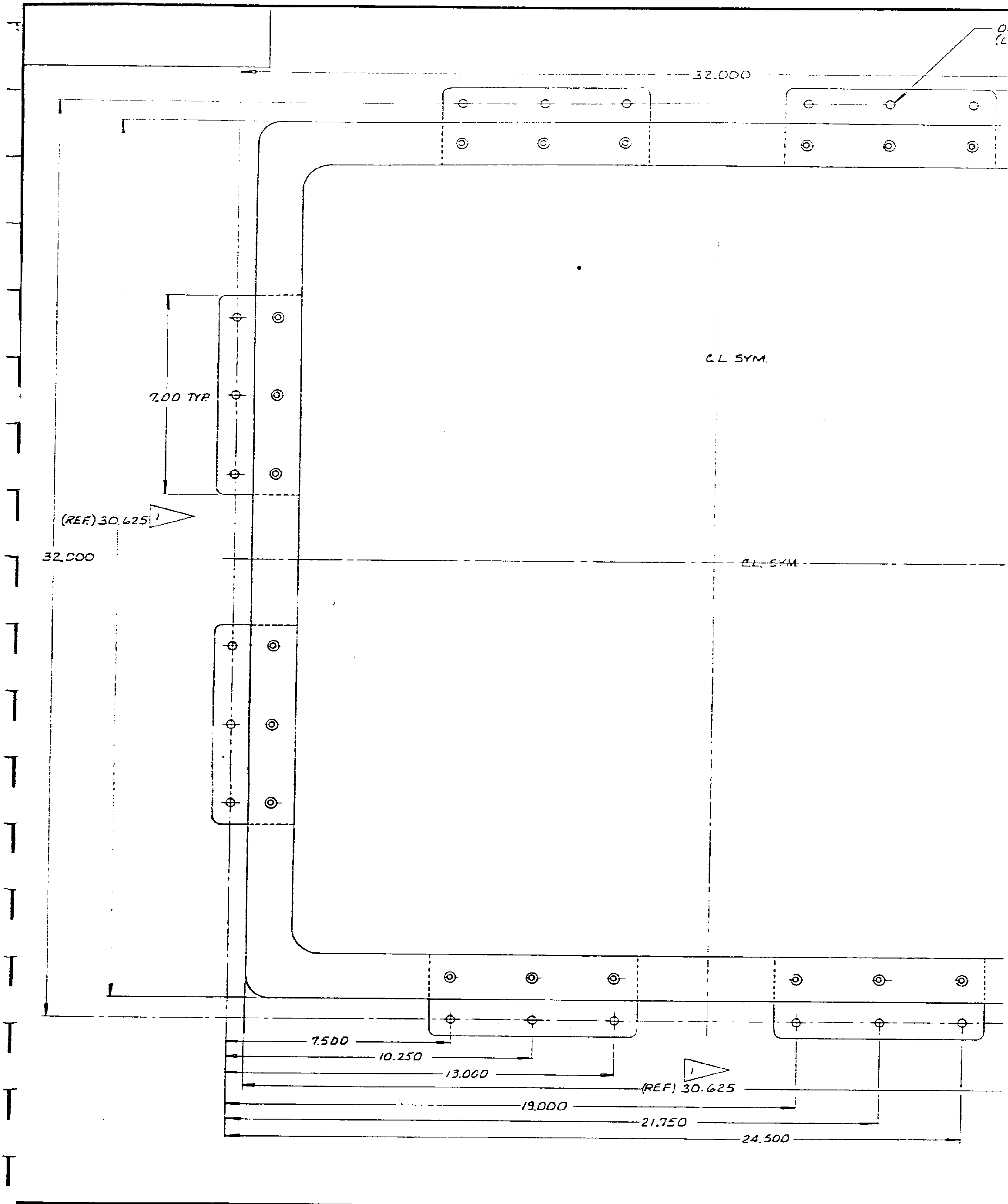
ASSEMBLY, OUTER FRAME

SRS TECHNOLOGIES
Systems Technology Group
990 Explorer Blvd., NW
Huntsville, AL 35806

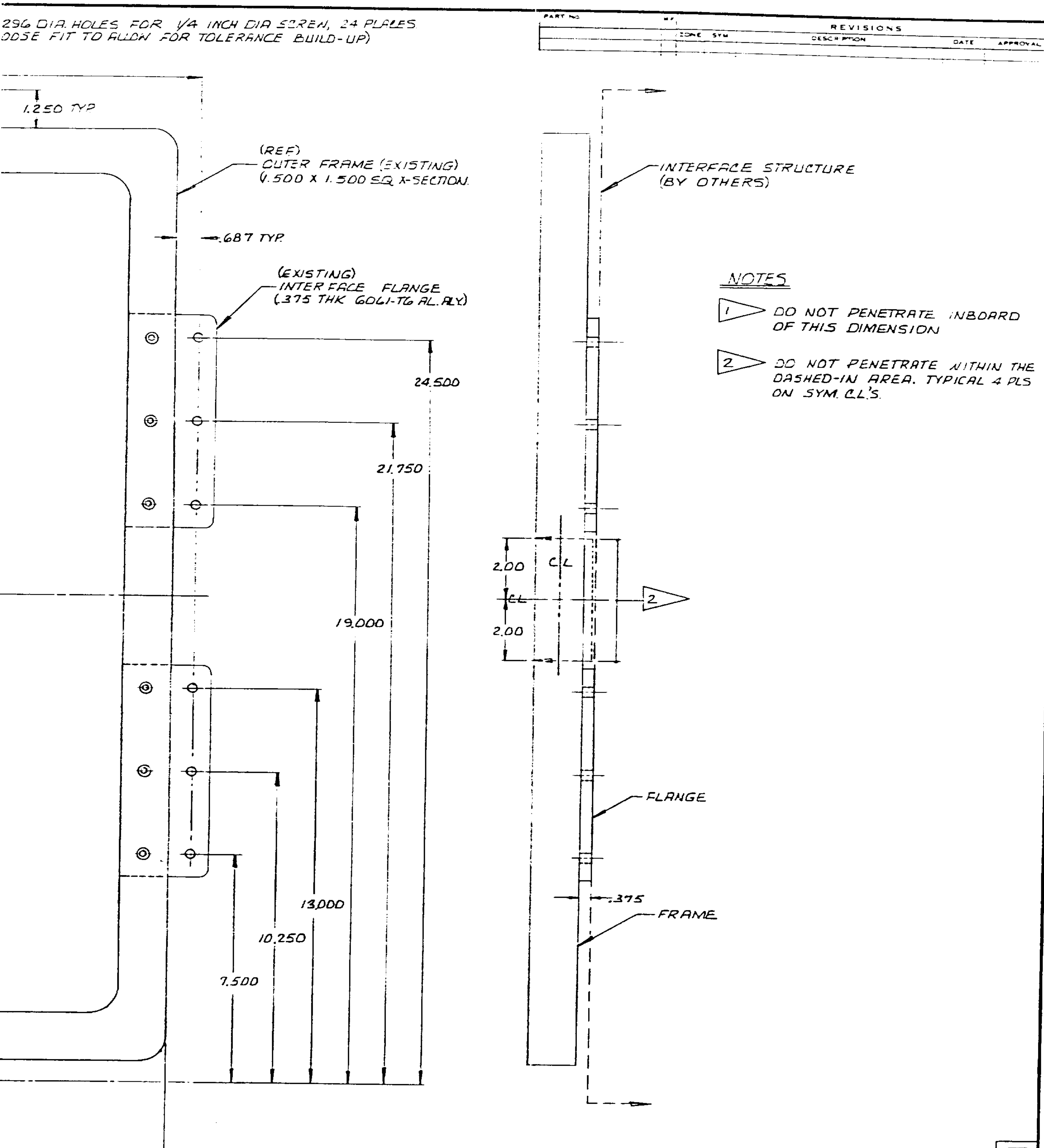
DWG SIZE: D | 5490-11-03

SCALE: 1/2 | WEIGHT: 34.5 LBS | SHEET 1 OF 1

FOLDOUT FRAME 2



FOLDOUT FRAME



[redacted]	
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS XX=±.02 XXX=±.010
MATERIAL
HEAT TREATMENT
FINAL PROTECTIVE FINISH

ORIGINAL DATE OF DRAWING 10-9-90
DRAFTSMAN GC
CHECKED
CHECKER PG
STRESS JM
ENGINEER PG
GROUP ENGINEER GP
SUBMITTED PAUL GIEROW
APPROVED

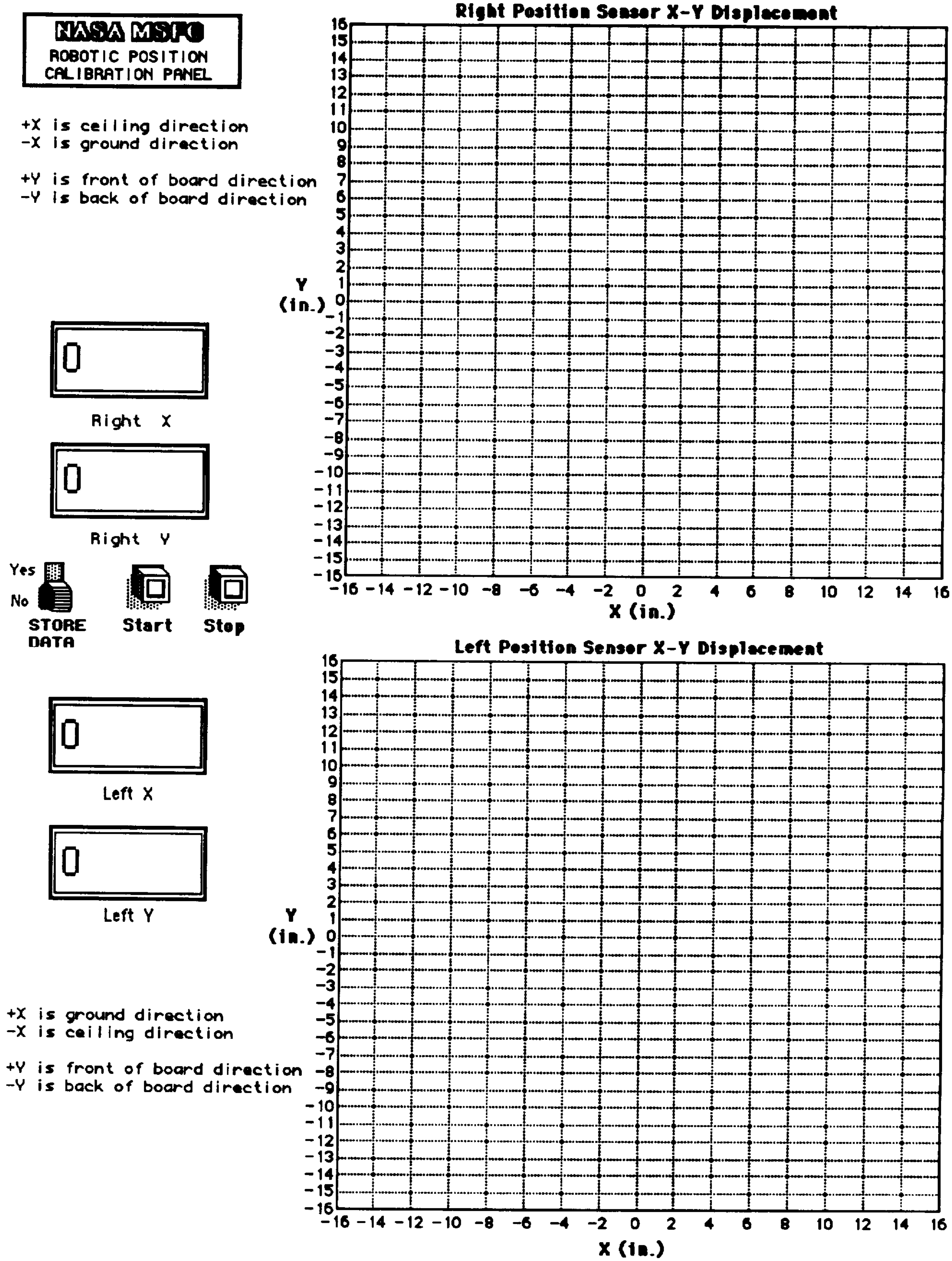
INTERFACE DIMENSIONS
FLUID SUPPORT FRAME

SRS TECHNOLOGIES
Systems Technology Group
990 Explorer Blvd., NW
Huntsville, AL 35806

DWG SIZE D 5490-11-04
WEIGHT CHECKED
DATE
CODE
SCALE 1/2
UNIT WEIGHT
SHEET 1 OF 1

FOLDOUT FRAME 2

2-D TRACKING FRONT PANEL (LABVIEW)



"2-D Tracking Inst." Front Panel